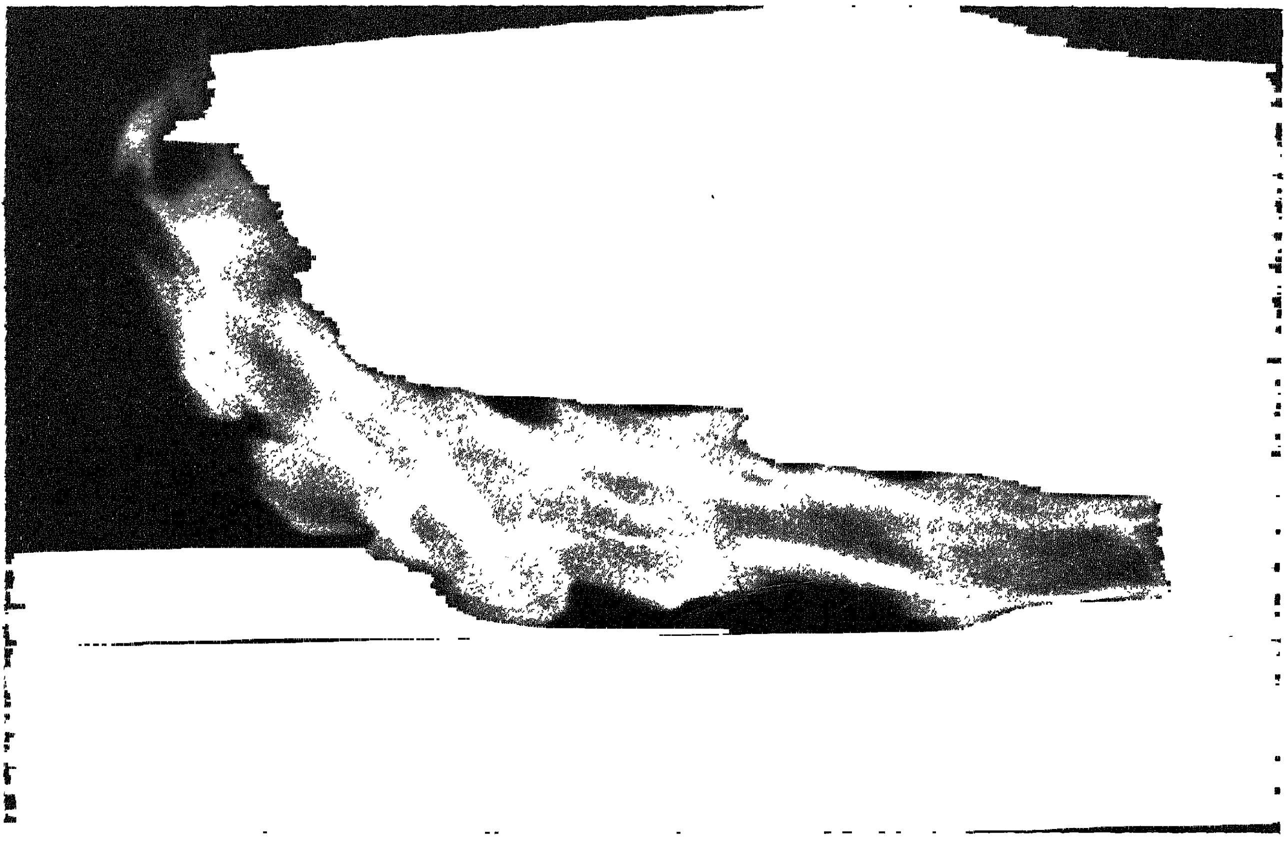
DESIGN, FABRICATION, TESTING AND FIELD DEMONSTRATION OF BIOMASS GASIFIER SYSTEMS FOR IRRIGATION PUMPING

FINAL REPORT

Submitted to

Department of Nonconventional Energy Sources
14, C.G.O. Complex, Lodi Road
New Delhi - 110 003



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Project Team

Dr. V.V.N. Kishore	(Principal Investigator)
Mr. P. Raman	(Mar 1986 - Sept 1990)
Ms. Sangeetha Kohli	(Mar 1986 - Oct 1988)
Mr. V.L.N. Murthy	(July 1988 - Dec 1989)
Dr. S.D. Sharma	(July 1988 - Mar 1990)
Mr. Sunil Dhingra	(Aug 1989 - Sept 1990)

Technical Assistance :

Mr. Gurvinder Singh

Mr. Manjit Singh

Mr. U. Vellaikkannu

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1. INTRODUCTION

In the original proposal [1] of the project submitted to DNES in 1986, the following objectives were spelt out.

Main objectives :

- Design and fabrication of a small capacity biomass gasifier.
- Laboratory testing of the system and analysis of data as feedback into design.
- Field testing in rural areas.

Secondary objectives :

- Development of a suitable method of aggregating loose biomass and to find the most suitable fuel.
- Combination of fuels for the prevailing local availability
- Development of an effective ash removal system.
- Development of a simple and effective system for cooling and cleaning of the gas.

All the above objectives have been achieved. The findings of the investigations carried out in the project are discussed in the following chapters.

2. DESIRABILITY OF USING WOOD FOR GASIFICATION

The interest in small size wood gasifiers coupled to Diesel pumps (3-7 HP) in India started gaining momentum since the work carried out at Jyoti Solar Energy Research Institute (presently Sardar Patel Renewable Energy Research Institute), Vallabh Vidyanagar. Commercial production of the wood gasifier units started subsequently, and at present there are about half a dozen manufacturing firms in India. In recent years the DNES launched a nation wide programme for the demonstration of wood gasifier systems, under which about 300 units have been installed so far. The results of this demonstration exercise are not yet completely known, but some doubts are being raised as to the wisdom of using wood as gasifier fuel, particularly in view of the increasing scarcity of wood in many parts of the country. The argument for the wood gasifier systems is, and has been, that the gasifier programme should be coupled with the Social/Agro forestry programmes. In any case, wood is no longer a cheap biomass fuel and a cost is associated with the procurement/production of wood. Hence it becomes necessary to carry out a detailed economic analysis of wood gasifier systems. Such an analysis has been carried out in the initial stages of this project. This work is now published [2], and is enclosed in the Appendix. The method of analysis uses the Levelised Annual Cost (LAC) as an index to compare the economic viability of wood gasifier systems with conventional diesel pumping systems. A factor f, defined as the ratio of the levelised annual costs for wood gasifier and diesel pumping systems, has been computed for various parameters such as the discount rate (r), cost of wood including the cutting costs (C_w+y), number of operating

Table 2.1 : Sensitiviy of f for r = 0.12

N \ $C_w + Y$	0.2	0.4	0.6	0.8	1.0
			$I_2 = 25{,}000;\ C_d = 3.5$		
500	1.76	1.88	2.00	2.13	2.25
1000	1.32	1.47	1.63	1.78	1.94
1500	1.11	1.28	1.45	1.62	1.79
2000	0.99	1.17	1.35	1.53	1.71
2500	0.91	1.10	1.28	1.47	1.65
3000	0.86	1.05	1.24	1.43	1.62
			$I_2 = 25{,}000;\ C_d = 4.4$		
500	1.58	1.68	1.79	1.90	2.00
1000	1.16	1.29	1.42	1.55	1.68
1500	0.98	1.12	1.26	1.40	1.54
2000	0.87	1.02	1.17	1.32	1.46
2500	0.81	0.96	1.11	1.26	1.41
3000	0.76	0.92	1.07	1.22	1.38
			$I_2 = 25{,}000;\ C_d = 4.8$		
500	1.51	1.61	1.71	1.81	1.91
1000	1.11	1.23	1.35	1.47	1.60
1500	0.93	1.06	1.20	1.33	1.46
2000	0.84	0.96	1.11	1.24	1.38
2500	0.77	0.91	1.05	1.19	1.33
3000	0.73	0.87	1.01	1.16	1.30
			$I_2 = 20{,}000;\ C_d = 3.5$		
500	1.53	1.66	1.78	1.90	2.02
1000	1.17	1.33	1.48	1.64	1.79
1500	1.01	1.18	1.35	1.52	1.69
2000	0.91	1.09	1.27	1.45	1.63
2500	0.85	1.03	1.22	1.40	1.59
3000	0.80	0.99	1.18	1.37	1.56
			$I_2 = 20{,}000;\ C_d = 4.4$		
500	1.38	1.49	1.59	1.70	1.80
1000	1.04	1.17	1.30	1.43	1.56
1500	0.89	1.03	1.17	1.31	1.46
2000	0.81	0.95	1.10	1.25	1.39
2500	0.75	0.90	1.05	1.20	1.36
3000	0.71	0.87	1.02	1.18	1.33
			I_2 = 20,000; Cd = 4.8		
500	1.32	1.42	1.52	1.62	1.72
1000	0.99	1.12	1.24	1.36	1.48
1500	0.85	0.98	1.11	1.24	1.38
2000	0.77	0.91	1.04	1.18	1.32
2500	0.72	0.86	1.00	1.14	1.28
3000	0.68	0.83	0.97	1.11	1.25

Table 2.2 : Sensitivity of f for r = 0.09

N \ C_w + Y	0.2	0.4	0.6	0.8	1.0
I_2 = 25,000; C_d = 3.5					
500	1.66	1.79	1.91	2.04	2.17
1000	1.24	1.40	1.56	1.72	1.88
1500	1.05	1.23	1.40	1.57	1.75
2000	0.94	1.12	1.31	1.49	1.67
2500	0.87	1.06	1.25	1.44	1.62
3000	0.82	1.01	1.21	1.40	1.59
I_2 = 25,000; C_d = 4.4					
500	1.48	1.59	1.70	1.81	1.92
1000	1.09	1.23	1.36	1.49	1.63
1500	0.93	1.07	1.21	1.36	1.50
2000	0.83	0.98	1.13	1.28	1.43
2500	0.77	0.93	1.08	1.23	1.38
3000	0.73	0.89	1.04	1.20	1.35
I_2 = 25,000; C_d = 4.8					
500	1.42	1.52	1.63	1.73	1.83
1000	1.04	1.17	1.29	1.42	1.54
1500	0.88	1.02	1.15	1.28	1.42
2000	0.80	0.93	1.07	1.21	1.35
2500	0.74	0.88	1.02	1.16	1.30
3000	0.70	0.84	0.99	1.13	1.27
I_2 = 20,000; C_d = 3.5					
500	1.46	1.58	1.71	1.84	1.97
1000	1.12	1.27	1.43	1.59	1.75
1500	0.96	1.13	1.31	1.48	1.66
2000	0.87	1.05	1.24	1.42	1.60
2500	0.81	1.00	1.19	1.38	1.56
3000	0.77	0.96	1.16	1.35	1.54
I_2 = 20,000; C_d = 4.4					
500	1.31	1.42	1.53	1.64	1.75
1000	0.99	1.12	1.26	1.39	1.52
1500	0.85	0.99	1.14	1.28	1.43
2000	0.77	0.92	1.07	1.22	1.37
2500	0.72	0.88	1.03	1.18	1.34
3000	0.69	0.85	1.00	1.16	1.31
I_2 = 20,000; Cd = 4.8					
500	1.25	1.36	1.46	1.56	1.67
1000	0.94	1.07	1.19	1.32	1.44
1500	0.81	0.95	1.08	1.21	1.35
2000	0.74	0.88	1.02	1.16	1.29
2500	0.70	0.84	0.98	1.12	1.26
3000	0.66	0.18	0.95	1.09	1.24

The following conclusions emerge from an examination of the tables.

i) For all the combinations of parameters considered, gasifier based diesel pumps are economically not viable under the circumstances where $N \leq 2000$ hrs. and $(C_w+y) \geq 0.6$ Rs/kg.

ii) For $N \leq 1000$ hrs., the system is not viable at the present initial cost (I_2) for any of the interest rates, diesel prices and wood chip prices considered.

iii) For $(C_w+y) \geq 0.8$ Rs/kg, the system is not viable for any of the initial costs, discount rates, diesel prices and number of hours considered.

Further examination of the cost of wood grown in forestry programmes, shows that [2] the gasifier system is not viable economically for most of the combinations and would at best be marginally viable under the best circumstances of low capital cost, low discount rate and high diesel price. Economics need not be the sole criterion for a developing technology such as gasification, but from the point of view of increasing scarcity of wood, it is highly desirable to concentrate efforts on biomass other than wood for gasification purposes.

3. GASIFICATION OF BIOMASS OTHER THAN WOOD - A REVIEW AND EVALUATION OF VARIOUS FUELS

Reed [3] gave an up-to-date directory of gasifier research, development and manufacture based on responses to questionnaires, mainly in the United States of America. The list is already 10 years old, but a careful look at the compiled information shows that the majority of the efforts were directed at producing low/medium energy gas as an end product for industrial applications. A partial list for air gasification is given in Table 3.1. It is apparent from the Table that systems/processes have been designed and operated to gasify a variety of biomass fuels such as corn cobs, saw dust, animal and agricultural residues etc. Also, many of these are large scale systems, with features such as continuous feedings, ash removal, extensive cleaning of gas, controls at various points etc. Technical information on many of these systems is not available except in a sketchy manner.

Table 3.1 : Partial list for air gasification (Ref. 3)

Organization	Gasifier type				Size
	Input	Contact Mode	Fuel Products	Operating Units	Btu/h
Air Gasification of Biomass					
Alberta Industrial Dev. Edmonton, Alb., Can.	A	F1	LEG	1	30M
Applied Engineering Co., Orangeburge, SC 29115	A	U	LEG	1	5M
Battelle-Northwest Richland, WA 99352	A	U	LEG	1-D	--

Contd..next page

(Table 3.1 continued)

Organization	Gasifier type				Size
	Input	Contact Mode	Fuel Products	Operating Units	Btu/h
Century Research Inc. Gardena, CA 90247	A	U	LEG	1	80M
Davy Powergas, Inc. Houston, TX 77036	A	U	LEG-syngas	20	--
Deere & Co. Moline, IL 61265	A	D	LEG	1	100kW
Eco-Research Ltd. Willodale, Ont N2N 558	A	F1	LEG	1	16M
Forest Fuels, Inc. Keene, NH 03431	A	U	LEG	4	1.5-30M
Foster Wheeler Energy Corp. Linvingston, NH 07309	A	U	LEG	1	--
Fuel Conversion Project Yuba City, CA 95991	A	D	LEG	1	2M
Halcyon Assoc. Inc. East Andover, NY 95991	A	U	LEG	4	6-50M
Industrial Dev. & Procurement Inc. Carle Place, NY 11514	A	D	LEG	Many	100-750kW
Pulp & paper Res. Inst., Pointe Claire,Quebec H9R 3J9	A	D	LEG	-	--
Agricultural Engr. Dept. Purdue University W. Lafayette, IN 47907	A	D	LEG	1	0.25M
Dept. of Chem. Engr. Texas Tech University Lubbock, TX 79409	A	F1	LEG	1	0.4M
Dept. of Chem. Engr. Texas Tech University Lubbock, TX 79409		U	LEG	1	--
Vermont Wood Energy Corp. Stowe, VT 05672	A	D	LEG	1	0.08M

Contd..next page

(Table 3.1 continued)

Organization	Gasifier type				Size
	Input	Contact Mode	Fuel Products	Operating Units	Btu/h
Dept. of Ag. Engr. Univ of California Davis, CA 95616	A	D	LEG	1	64,000
Dept. of Ag. Engr. Univ of California Davis, CA 95616	A	D	LEG	1	6M
Westwood Polygas (Moore)	A	D	LEG	1	
Bio-Solar Research & Dev. Corp. Eugene, OR 97401	A	U	LEG	1	--
Air Gasification Solid Municipal Waste (CSMW)					
Andco-torrax[b] Buffalo,NY	A	U	LEG	4C	
Battele NW Richmond,VA 99352					

---

[b] Unless noted otherwise, the gasifiers listed here produce dry ash (T < 1100C) and operate at 1 atm pressure.

[c] Operates at 1-3 atm pressure.

Input : A = air gasifier; O = Oxygen gasifier; P = pyrolysis process; PG = Pyrolysis gasifier; S = Steam; C = char combustion

Contact mode : U = updraft; D= downdraft; O = other (sloping bed, moving grate); Fl = Fluidized bed; S = suspended flow; MS = molten salt; MH = multiple hearth

Fuel products : LEG = low energy gas (~150-200 Btu/SCF) produced in air gasification; MEG = medium energy gas produced in oxygen and pyrolysis gasification (350-500 Btu/SCF); PO = pyrolysis oil, typically 12,000 Btu/lb; C = char, typically 12,000 Btu/lb

Operating Units: R = research; P = pilot; C = commercial size; CI = commercial installation; D = demonstration

Size : Gasifiers are rated in a variety of units. Listed here are Btu/h derived from feedstock throughput on the basis of biomass containing 16 MBtu/ton or 8000 Btu/lb, SMW with 9 MBtu/ton. ( ) indicate planned or under construction.

Extensive tests conducted at the University of California, Davis, as mentioned in the report by Kaupp (4), showed that several biomass residues, either in natural form or in briquetted form, can be gasified successfully in the same gasifier. The reliability of operation was however, not the same for all fuels. Fuels in natural form which could be used for a 6 hr continuous period were - 1. hard-shell almond shells, 2. soft shell almond shells, 3. cracked walnut shells, 4. olive pits, 5. peach pits, 6. prune pits and 7. broken corn cobs. Other fuels such as rice hulls, sawdust, cotton gin trash etc., could be used successfully in the UCD gasifier after pelletizing or cubing. However, slag formation has been reported in fuels with ash contents above 6% in general. Fuels which have been classified as slagging fuels were barley straw mix, bean straw, corn stalks, cotton gin trash, cubed cotton stalks, residue derived fuel (RDF) pellets, pelleted rice hulls, safflower straw, pelled walnut shell mix etc. However, no attempts were made to keep the temperature of the fire zone below the melting point of the ash.

Gasification of rice hulls has been extensively discussed by Kaupp (5). Inspite of the high ash content of rice hulls and the consequent classification as a "slagging fuel", rice hull gasifiers had been working satisfactorily for years in Italy and China. The Italian Balestra type gasifier was a suction updraft gas producer. The gasifier, with an output of about 160 m^3/hr was used to drive an engine. Though the rating of the engine is not known, outputs of 25-60 hp were mentioned. The gas engine powered all equipment in the rice mill. Not all the gas which was generated could be used and some was simply flared off. The rice hull gasification plant in Suzhou, Jiangsu province, China, was downdraft type and was also used to power an engine. The specific gas consumption was reported to be 5.1 m^3/kW h. Some work on rice hull gasification was done at Punjab Agricultural University, Ludhiana [6]. Problems faced such as arching, could not be solved successfully and the R & D work did not lead to commercialisation of rice husk gasifiers. Efforts were also made to gasify corn cobs, arhar stalks, cotton stalks and groundnut shell directly in a 50 mm throated gasifier, but continuous operation was not possible due to choking over the throat. A conclusion was therefore arrived in 1983 that it was impractical to design downdraft gasifiers for operation on crop residues in the small size range and further work was given up.

A gasifier system using chared corn cobs was developed by I.I.T./Delhi under a joint Indo-American project [7]. A 2.5 kW system for irrigation pumping was installed at the village Sankrood, 48 km from Delhi and the system logged 100 hours in 1986. This design, however, has not yet been commercialized.

Gasification of rice husk in a fluidised bed was attempted at the Bharatidasan School of Energy, Tiruchirapalli [8]. The gas obtained was, however, of a poor quality (10% CO) and problems identified were those related to air and fuel flow.

A throatless gasifier utilising sugar cane leaves has been developed at the Nimbkar Agricultural Research Institute, Phaltan, but the design and performance details are not yet available.

To sum up, sustained efforts on gasification of non-wood biomass are extremely scarce. Large scale systems utilising rice husk, for example, seem to be more amenable for continuous operation than the smaller systems. As summarised by Kaupp and Goss, "Commercial gasification as practiced for the last 140 years has avoided problematic fuels, those high in ash or with a tendency for slagging, because of the difficulties involved in achieving reliable operation over a continuous period without too much attention to the gasifier."

3.1 Evaluation of various fuels for gasification :

There is a considerable amount of discussion in the literature regarding the suitability of various fuels for gasifier applications. Also the various physical and chemical properties of the fuel which have to be examined carefully before designing a suitable gasifier have been explicitly identified. The general classification separates biomass fuels into slagging and non-slagging type. It is generally agreed that for a particular fuel to be a suitable candidate for gasification, i) the calorific value should be high, ii) the ash content should be low, iii) moisture content should be low and iv) the ash melting point should be low. Though these properties are available in literature for different biomass materials, regional variability in the quality of biomass and local climate cause a significant variation in these properties.

For the purpose of evaluating various fuels for gasification, a separate effort was made to measure as many relevant properties as possible in the initial stages of the project. A Toshniwal oxygen bomb calorimeter with a Beckmann thermometer was employed for estimation of the calorific value. Moisture content and ash content was measured using standard techniques. For finding out the ash melting point, the ash was heated in a crucible in steps of 100°C. After each incremental step, the sample was cooled down and examined for any fusion of ash. A total of 13 fuels were evaluated initially. The list of fuels alongwith the properties measured is given in Table 3.2.

A method of weighted scores was also developed and applied to the various fuels [9] in order to obtain some sort of grading among the fuels. A compound score incorporating the measured properties of the fuel and the relative importance of each property, was worked out for the sake of comparison. Table 3.3 gives the final score.

Table 3.2 : Properties of Different Fuels

Fuel	Calorific value kcal/kg (% deviation)	Ash content % by Wt. (% deviation)	Moisture content % by Wt.	Ash melting point deg^{o}C
1. Pure cattle dung	3595 (0.5)	20.2 (0.7)	8.0	900-1000
2. Cattle dung cake	3022 (0.5)	38.4 (7.8)	7.6	900-1000
3. Cattle dung + sawdust Dry wt. basis)	3610 (1:2)	25.0 (0.6)	8.3 (11.3)	900-1000
4. Groundnut shell	4334 (1.2)	15.2 (2.6)	10.9	> 1000
5. Wheat straw	4148 (2.1)	8.1 (10.0)	8.9	900-1000
6. Mustard Stalk	4507 (0.7)	2.9 (6.9)	11.3	> 1000
7. Sawdust	4720 (3.8)	10.0 (7.2)	8.0	1000
8. Wheat Boor	4280 (0.9)	4.4 (2.1)	9.7	< 900
9. Rice Husk	3474 (1.2)	17.2 (1.9)	9.6	> 1100
10. Coal powder	3388	50.1	5.4	> 1000
11. Pearl Millet (Bajra cob)	4234 (2.1)	4.7 (4.0)	7.3	< 900
12. Sorghum Stalk	4040 (2.4)	3.5 (11.6)	9.5	900-1000
13. Cattle Dung + Coal Powder (1:9 on dry wt. basis)	3676 (1.6)	47.8 (2.9)	2.9	> 1000

* kcal value, ash content and moisture are on dry basis.

Table 3.3 : Calculation of final, compound score for each fuel

Fuel	Calorific value kcal/kg (W1=0.467) S1	Ash content (W2 = 0.333) S2	Moisture content (W3 = 0.1333) S3	Ash melting (W4 = 0.067) S4	Score S =S1 W1 + S2W2 + S3W3 + S4W4
1. Pure cattle dung	2.98	6.63	6.0	5	4.73
2. Cattledung Cake	0.11	3.6	6.2	5	2.41
3. Cattledung+ Sawdust	3.05	5.83	5.85	5	4.48
4. Groundnut Shell	6.67	7.47	4.55	10	6.87
5. Wheat straw	5.74	8.65	5.55	5	6.63
6. Mustard Stalk	7.54	9.52	4.35	10	7.94
7. Sawdust	8.6	8.33	6.0	5	7.92
8. Wheat Boor	6.4	9.27	5.15	0	6.76
9. Rice Husk Briquettes	2.37	7.13	5.2	10	4.84
10. Coal Powder	1.94	1.65	7.3	10	3.10
11. Pearl Millet (Bajra) Cob	6.17	9.22	6.35	0	6.80
12. Sorghum Stalk	5.2	9.42	5.25	5	6.93
13. Coal Powder+ Cattledung	3.38	2.03	8.55	10	4.06

It can be seen from this table that mustard stalk gets the highest score, followed by saw dust, sorghum stalk, groundnut shells, bajra cobs etc. The fuels from the bottom upwards are dung cake, coal dust, briquettes of coal dust and dung etc. It should however be emphasized that this method of grading is still not adequate, as parameters such as fuel size, void fraction, bulk density etc. are not taken into account in this study. Also, assigning of weights to different parameters was somewhat subjective. For a more comprehensive evaluation, the relative importance of each of the parameters for continuous and trouble-free operation of the gasifier should be quantified in some way or other and then only weights should be assigned. It should be mentioned here that much more detailed thermo-chemical characterisation of several biomass residues had been carried out at I.I.T. Delhi [10,11]. However, the exercise of incorporating this valuable data into an engineering design practice of gasifiers is yet to be attempted. There is also a need to study the flow properties of solid biomass materials as one of the most important problems in downdraft gasifiers utilising biomass is related to the flow of biomass within the reactor.

Any number of biomass residues can be evaluated as mentioned above, and several of these residues might be excellent materials for gasification. But from a practical point of view, a very careful assessment has to be made regarding the availability of these materials in quantities sufficient for useful gasifier applications. Several of these residues are available only in particular seasons. From the availability point of view, only mill residues such as rice husk, saw dust, groundnut shells etc. become suitable candidates for gasification. Non-fodder seasonal field residues such as mustard stalks, cotton stalks, arhar stalks etc. can be utilised for rural applications only if these can be accepted in the same gasifier. This brings us to the important aspect of the design of gasifier systems.

4. A CRITIQUE OF DESIGN PHILOSOPHY OF BIOMASS GASIFIERS AND ASSOCIATED SUBSYSTEMS.

The discussion in this section will be limited to downdraft gasifiers as we are primarily interested in gasifiers for engine applications. Although updraft gasifiers had been used for engine applications, such as the Italian Balestra type rice hull gasifier, updraft gasifiers are considered not suitable for engine applications as they produce substantial amounts of tar, necessitating an elaborate gas cleaning system. The most complete set of design rules necessary for fabricating gasifiers pertain to the Imbert type gasifiers of the second world war operating on wood or charcoal. These rules had evolved through practical experience and do not seem to have any theoretical basis and hence can be considered as purely empirical. Several workers in gasification have extensively used the rules laid down in the Gengas book, but it will be shown later that there still exists a considerable amount of uncertainty and confusion, even for designing wood-based, downdraft gasifiers of the throated type.

The first step in designing a gasifier consists of calculating the maximum demand of producer gas needed to run an IC engine of a given type and a given rated horsepower. The rate at which producer gas-air mixture is sucked into the engine cylinder is proportional to the cylinder volume, engine rpm and the filling efficiency of the cylinder. For naturally aspirated engines, a filling efficiency of 80-85% is usually taken and for turbocharging systems, the efficiency can be 100%. For a four-stroke petrol engine with a cylinder volume $V(m^3)$ and rpm N, the amount of gas-air mixture sucked assuming a filling efficiency of 85%, is given by

$$V_{mix} = \frac{0.85\ VN}{2} \times 60 \quad (m^3/hr) \qquad \ldots(4.1)$$

For a diesel engine, however, 100% producer gas operation is seldom feasible and the above formula will then yield the gas-air mixture rate including the air required for combustion of diesel also. The amount of air needed for complete combustion of producer gas obtained in wood fueled, air gasifiers is roughly in a 1:1 proportion to the gas. Hence, for petrol engines, the volumetric rate of gas required is

$$V_g = V_{mix}/2 \qquad \ldots(4.2)$$

and for diesel engines, the producer gas demand is

$$V_g = (V_{mix} - V_{air,\ diesel})/2 \qquad \ldots(4.3)$$

The quantity $V_{air,\ diesel}$ has to be obtained by assuming a diesel replacement value and the specific consumption value. For example, a 5 hp diesel engine with a specific consumption of 200 g/hp h and with an assumed value of 80% diesel replacement would need a $V_{air,\ diesel}$ value of

$$V_{air,\ diesel} = 5 \times 200 \times (1-0.8) \times 20/1000 \ (kg/hr) \qquad \ldots(4.4)$$

It is always recommended that the producer gas demand be calculated in the above manner, but some workers had adopted a different method. The latter method relies on assuming a mechanical efficiency of the engine. For example Gaur et. al. (12) calculated their producer gas demand for a 3.7 kW engine, with an assumed value of 20% engine efficiency as

$$\frac{3.7 \text{ kW}}{0.2 \times 1.4 \ (\text{kWh/Nm}^3)} = 13.2 \ \text{Nm}^3/\text{hr}$$

It can be shown that the above method of calculation is not strictly correct and yields higher values of gas requirements for diesel systems. If P is the rated power output in kW, M_d is the diesel consumption rate in kg/hr, V_g is the gas consumption in Nm^3/hr, and $(CV)_d$ and $(CV)_g$ are the calorific values of diesel (kWh/kg) and gas (kWh/m^3) respectively, the efficiency of the engine (with no derating) is given by

$$\eta = \frac{P}{M_d \ (CV)_d + V_g \ (CV)_g} \qquad \ldots(4.5)$$

The above equation can be rearranged as

$$V_g = \frac{P}{(CV)_g} - M_d \frac{(CV)_d}{(CV)_g} \qquad \ldots(4.6)$$

The procedure adopted by Gaur et. al. takes into account only the first term in the above equation and ignores the second term, giving a gas demand which is in excess of requirements by about 14%, ultimately leading to an oversizing of the gasifier. With so many other parameters affecting the performance of the gasifier-engine system, some oversizing of the gasifier may not be a serious matter, but the above point serves to illustrate the not-so-rigorous-engineering-approach when it comes to designing biomass gasifiers. It is, however, apparent that gas demand calculated by eq (4.6) above will be less accurate as the number of assumptions are more and hence eqs (4.1) - (4.3) would be more reliable in computing the gas demand.

As the volume of gas needed is a function of temperature and pressure, it is customary to calculate the gas demand at STP (0^oC, 1 atm) and express the demand in Nm^3/hr.

Before going in for design calculations of the gasifier and associated systems, it is customary to calculate the composition of producer gas, air-fuel ratio and specific consumption of biomass. Biomass consists of carbon, hydrogen and oxygen, alongwith some ash and moisture. From a knowledge of the elemental analysis of the biomass, it is possible to calculate the equilibrium composition of producer gas as a function of oxygen supply by applying the principles of chemical thermodynamics [4]. The oxygen supply is usually expressed as an equivalence ratio (ER), defined as

$$ER = \frac{\text{Weight of (Oxygen/Dry Fuel)}}{\text{(Oxygen/fuel)}_{\text{stoichiometric}}} \qquad \ldots(4.7)$$

The equivalence ratio defined in eq (4.7) varies from 0 to 1, corresponding to no combustion and complete combustion respectively. For gasification, an ER value of about 0.3 seems to be adequate. For ER less than 0.3, pyrolysis dominates and for ER greater than 0.3, combustion prevails. The practical range of ER for gasifiers is between 0.2 to 0.4. It is also known that on a moisture-and-ash-free (MAF) basis, almost all biomass residues have the same composition in terms of C, H and O [4]. With the narrow range of oxygen supply needed and with the relatively invariant composition of biomass, it can be expected that the composition of producer gas obtained from several biomass fuels would be roughly the same, provided the gasifier design allows for sufficient reaction times and temperatures. To corraborate this point, the measurements made by Jenkins [13] on several biomass residues are given in Table 4.1. It can be seen that the CO concentration varied from 15.7 - 28.7%, H_2 concentration varied from 9.6-18.4% and CO_2 concentration varied from 6.7-14.7%. Though the variation between the lowest and highest concentrations of a single species is as high as about 100%, a closer look at the table reveals that there is a strong probability distribution. For example, the CO concentration varied between 18-24 (a 33% variation) for 75% of the fuels studied. Larger variations can be attributed to differences in gas residence times. From the above discussion it is apparent that while dealing with different biomass residues, chemical kinetic considerations may not be very important in designing the gasifier, as long as sufficient gas residence times and temperatures are ensured. The aspect of gas residence time will be discussed later. Chemical thermodynamic (equilibrium) considerations are, however, warranted. The equilibrium calculations (elaborated, for example, in ref. 4), also yield values of biomass consumption rate for a given gas demand, and the resulting biomass flow rates have often been used to decide the dimensions of the fuel bin (hopper), and more importantly in the economic calculations. A figure of about 2.5 Nm^3/kg is obtained, for example, for simplified equilibrium calculations for wood. With a producer gas density of about 1.09 kg/Nm^3, the gas/fuel ratio on a weight basis would work out to 2.73 kg/kg. The data of Jenkins (Table 4.1), shows that the actual value is lesser at 2.1 kg/kg for most biomass fuels including wood. The gas output data of Jenkins was obtained from several calculations, including orific meter measurements, carbon balance, N_2 balance etc. and it had been pointed out that orifice measurements do not always give the correct value. The most consistent values were obtained by a carbon balance and the values shown in Table 4.1 were thus obtained. There are instances where the reported gas/fuel ratios are as high as 5.6 kg/kg (4.3 Nm^3/kg) as shown in Table 4.2.

Table 4.1 : Gasification characteristics of some California residues (Ref. 13)

Sl. No.	Fuel	Gas/fuel (lb/lb)	Fuel consumption (lb/hr)	Gas production rate (lb/hr)	Ash content (% wt,dry basis)	Bulk density (lb/ft^3)	CO	H_2	THC	CO_2	O_2	N_2
1.	Alfalfa Seed Straw	2.06	29.9	61.5	6.0	18.6	21.8	16.8	5.0	12.1	0	44.3
2.	Almond shell	2.14	49.7	106.2	4.8	11.7	18.3	16.8	6.3	13.8	0.1	44.7
3.	Barley straw (high)	2.13	30.6	65.3	10.3	18.7	20.9	13.4	5.2	10.9	0.1	49.5
4.	Barley straw (low)	2.16	9.2	19.9	10.3	18.7	21.7	16.4	4.5	10.6	0.4	46.4
5.	Bean straw	2.14	29.25	62.6	10.2	27.5	20.3	15.5	2.9	12.6	0.1	49.5
6.	Corn cobs (4" choke)	2.08	63.00	130.8	1.5	19.0	18.6	16.5	6.8	11.6	0.6	45.9
7.	Corn cobs (6" choke)	2.10	66.3	139.5	1.5	19.0	21.7	16.9	4.7	10.2	0	46.5
8.	Corn stalks	2.56	25.8	66.2	6.4	24.4	18.8	13.5	3.2	12.7	0.1	51.7
9.	Cotton gin trash	1.75	51.4	90.2	17.6	21.4	16.4	18.3	1.8	11.6	0	51.9
10.	Cotton stalks	2.26	22.8	51.6	17.2	16.2	15.7	11.7	3.6	14.7	0	54.3
11.	Olive pits	2.15	49.0	105.2	3.2	35.4	20.6	10.8	9.1	10.6	0.4	48.5
12.	Peach pits	2.49	29.83	74.4	0.9	29.6	25.2	16.5	2.9	9.9	0.1	45.4
13.	Prune pits	1.98	36.70	72.8	0.5	32.1	23.9	16.3	8.6	9.7	0	41.4
14.	RDF	2.25	20.2	45.5	10.4	26.5	19.4	13.4	8.6	7.8	0.3	50.5
15.	Rice hulls	3.03	35.25	106.7	-	42.4	16.1	9.6	1.0	10.5	0	62.8
16.	Safflower straw	2.08	28.62	59.4	6.0	12.7	21.2	16.5	4.2	13.2	0	44.9
17.	Walnut shell (cracked)	2.62	54.2	41.9	1.1	21.0	20.1	18.4	5.1	8.7	0.2	47.5
18.	Walnet shell (¼" pellets)	1.90	29.0	55.4	5.8	37.4	26.1	12.4	8.2	8.4	0.4	44.5
19.	Wheat straw (50/50 corn stalks)	2.11	27.5	58.1	7.4	12.4	22.0	15.5	4.4	11.4	0	46.7
20.	Wood blocks	2.79	22	61.3	0.2	16.0	22.5	14.2	4.7	10.8	0	47.8
21.	Wood chips (city tree prunings	2.08	39.3	81.6	3.0	11.3	18.8	16.4	5.0	13.7	0	46.1
22.	Wood chips (mfg, hogged)	2.09	22	46.1	0.3	10.4	28.7	13.8	6.8	6.7	0	44.0
23.	Wood chips (prune tree)	-	-	-	1.14	-	19.6	12.6	3.8	12.5	0.5	51.9
24.	Wood chips (whole log)	2.16	31.2	67.5	0.1	10.6	22.6	15.6	6.1	10.9	0.2	44.9

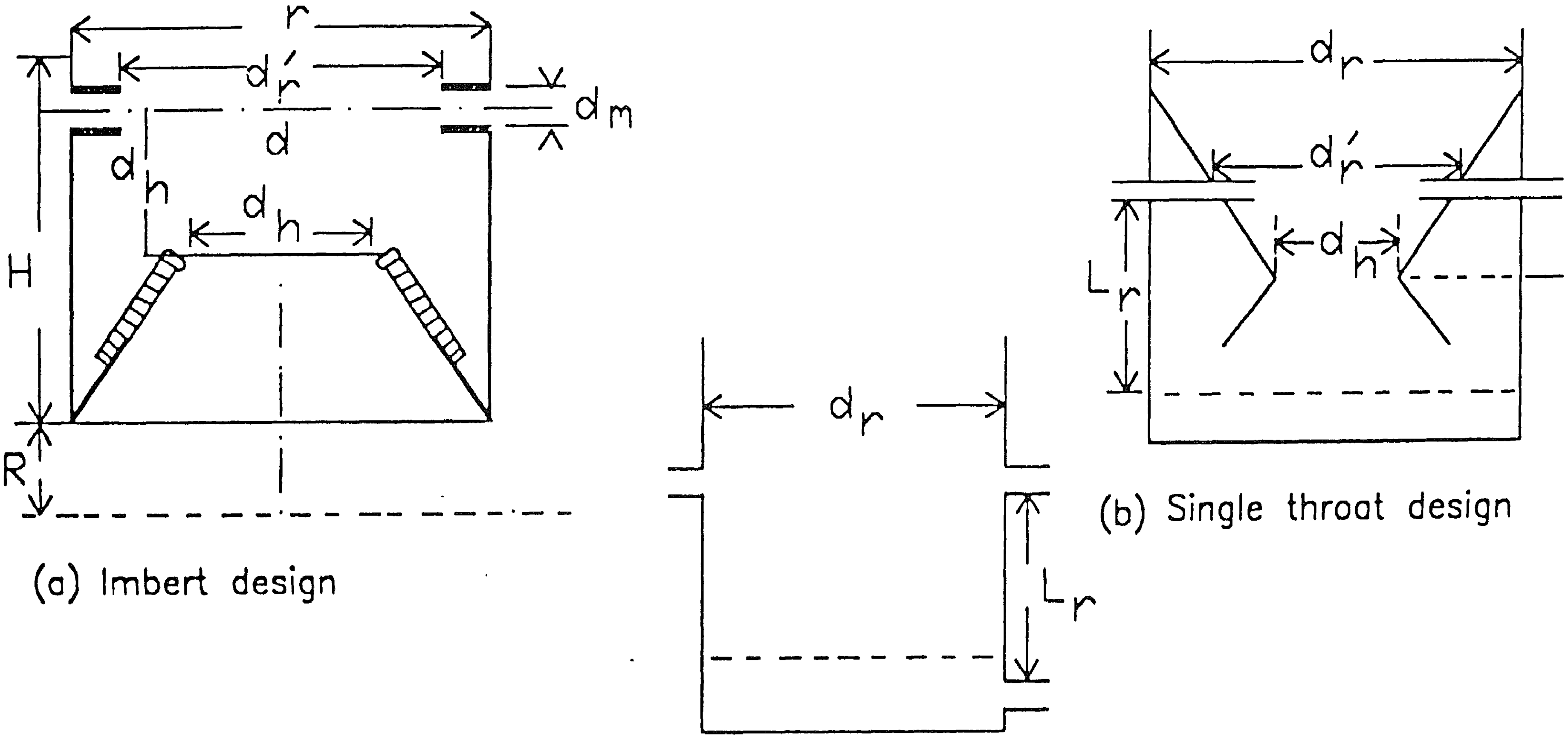
Table 4.2 : Gas/fuel and Air/fuel ratios obtained by equilibrium calculations and experimental results.

S. No.	Fuel	Equilibrium calculations				Experimental observations				Source
		Gas/fuel		Air/Fuel		Gas/fuel		Air/fuel		
		(Nm^3/kg) 1	(kg/kg) 2	(Nm^3/kg) 3	(kg/kg) 4	(Nm^3/kg) 5	(kg/kg) 6	(Nm^3/kg) 7	(kg/kg) 8	
1.	Wood chips (6% moisture)	-	-	-	-	2.07	2.075	-	1.35	M.P. Sharma etc. [14]
2.	Wood chips (12-18%)	-	-	-	-	4.17*	-	-	-	Rajvanshi [15]
3.	Wood chips (12-15%)	-	-	-	-	4.09-4.29	-	1.29-1.36	-	Parikh etc. [16]
4.	24 biomass residues	-	-	-	-	-	1.75-3.03	-	-	Jenkins [13]
5.	Wood chips	-	-	-	-	-	1.99-2.70	-	-	Dasappa etc. [17]
6.	Wood chips (18%)	-	-	-	-	-	-	-	1.81	Groeneveld [18]
7.	Wood chips (5.5-16.5%)	-	-	-	-	-	-	-	0.99-2.08	Walawender [19]
8.	Poplar (0-40%)	-	-	-	1.77-1.98	-	-	-	-	Chen and Gunkel [20]
9.	Wood chips (15%)	2.4	-	1.1	-	-	-	-	-	Schlapfer etc. [21]
10.	Rice hulls	-	-	-	-	1.65-2.34	1.25-1.58	-	1.28-2.10	Kaupp [4]
11.	Wood chips (dry)	2.31	-	1.58	-	-	-	-	-	Graf [23]

* Calculated from the reported wood consumption rate of 2.4 kg/hr and an assumed gas demand of 10 Nm^3/hr.

The equilibrium calculations with the proper ER values never yield such high figures. The cause of high gas/fuel ratios can be explained by i) faulty design of air nozzles whereby more than the required quantity of air enters the gasifier, ii) faulty measurements, or (iii) air leakages into the system. Values of gas/fuel ratios higher than those obtained from equilibrium calculations should hence be treated with caution. For design purposes, however, it would be a good practice to perform the equilibrium calculations for a given biomass rather than relying on published material with reference to gas/fuel and air/fuel ratios.

Essentially two designs, the throated and throatless type are currently available for fabricating downdraft gasifiers. The parameters for original Imbert type single throat design shown in fig 4.1 (a) underwent minor modifications such as the one shown in fig 4.1 (b) which replaces the choke ring with a continuous cone shaped design. Some designs used a choke plate while others changed the number of air tuyeres and the mode of air inlet. Nevertheless, the basic design method relies on the empirical dimensions given in the Gen-gas book and reproduced in Table 4.3. The design parameters compiled by Venselaar [22] and reproduced by Ulrich Graf [23] overlap those given in Table 4.3. Design parameters for throatless gasifiers are given by Reed and Das [24]. The parameters which are important for gasifier design are i) specific gasification rate (SGR), ii) diameter of the gasifier (d_r), iii) diameter of throat (d_h) iv) diameter at air inlet (d'_r), v) height of air inlet above throat (h), vi) total cross sectional area of air jet openings (Am), vii) number of tuyeres (A), viii) diameter of individual tuyeres (d_m), ix) air blast velocity (V_m), x) height of air inlet above the grate (L_r) and xi) height of the fuel bin. An additional parameter, the inclination of the walls of the



(a) Imbert design

(b) Single throat design

(c) Throatless design

Figure 4.1 : Parameters for gasifier design.

cone is sometimes specified, but fixing of all other parameters makes it irrelevant.

Table 4.3 : Imbert nozzle and hearth diameters

d_r/d_h	d_h mm	d_r mm	d_r mm	h mm	H mm	R mm	A No.	d_m mm	$\frac{A_m \times 100}{A_h}$	$\frac{d_r}{d_h}$	$\frac{h}{d_h}$	Range of Gas Output max Nm^3/h	Range of Gas Output min Nm^3/h	Maximum wood consumption kg/h	Air Blast Velocity Vm m/s
268/60	60	268	150	80	256	100	5	7.5	7.8	4.5	1.33	30	4	14	22.4
268/80	80	268	176	95	256	100	5	9.0	6.4	3.3	1.19	44	5	21	23.0
268/100	100	268	202	100	256	100	5	10.5	5.5	2.7	1.00	63	8	30	24.2
268/120	120	268	216	110	256	100	5	12.0	5.0	2.2	0.92	90	12	42	26.0
300/100	100	300	208	100	275	115	5	10.5	5.5	3.0	1.00	77	10	36	29.4
300/115	115	300	228	105	275	115	5	11.5	5.0	2.6	0.92	95	12	45	30.3
300/130	130	300	248	110	275	115	5	12.5	4.6	2.3	0.85	115	15	55	31.5
300/150	150	300	258	120	275	115	5	14.0	4.4	2.0	0.80	140	18	67	30.0
400/130	130	400	258	110	370	155	7	10.5	4.6	3.1	0.85	120	17	57	32.6
400/150	135	400	258	120	370	155	7	12.0	4.5	2.7	0.80	150	21	71	32.6
400/175	175	400	308	130	370	153	7	16.0	3.9	2.0	0.74	190	26	90	31.4
400/200	200	400	318	145	370	153	7	16.0	3.9	2.0	0.73	230	33	110	31.2

Variables not given in figure are defined as follows :

d_m = inner diameter of the tuyeres

A_m = sum of cross sectional areas of the air jet openings in the tuyeres.

A_h = cross-sectional area of the throat

A = number of tuyeres.

The above mentioned parameters, as listed in Table 4.3, were obtained empirically during second world war. There does not seem to be any need for deviating from these set-rules in designing gasifiers, but several researchers, especially in India, have arrived at a satisfactory design only after several years of trials with different [illegible]ometries and dimensions. An attempt is made in the following lines to examine the rationale, if any, followed by different researchers in designing gasifiers.

The first attempt to start active developmental work in wood gasifiers was made at the Sardar Patel Renewable Energy Research Institute (SPRERI), the erstwhile Jyoti Solar Energy Research Institute at Vallabh Vidya Nagar, Gujarat and was centered around developing a 5 hp wood gasifier-based diesel pumpset [25]. To date the emphasis remains on 5 hp irrigation pumping systems.

4.1 Specific Gasification Rate or Hearth Load :

The parameter used world wide for deciding the throat diameter is the specific gasification rate or hearth-load, defined as the volume of gas (at $0^{o}C$ and 1 atm) passing per unit area per unit time and expressed in the units of Nm^3/cm^2-hr. Once the gas demand is computed, the throat area can be obtained by dividing it by SGR. Evaluation of all other parameters is done easily enough from the data given in Table 4.3. The design data given in Table 4.3, is however, based on experience gained from operating gasifiers used to power automobiles. For running automobiles, the gas demand varies with speed and hence the gasifiers were required to provide a high 'turn-down ratio', defined as the ratio of highest to lowest gas production rates. While the upper limit was for delivering the maximum shaft power, the lower limit was for the idling speed of the engine. It is also clearly mentioned in the Gengas book that the gasifier should be designed for the maximum hearth load, which was specified as 0.9 Nm^3/cm^2 hr. The lower limit was about 0.1, yielding a turn down ratio of about 9. The pumping application, however, does not demand a high turn down ratio, but the gasifier still has to be designed for the maximum hearth load. For the 5 H.P. diesel pump in question, the maximum gas demand is about 10 Nm^3/hr, which would yield a throat area of 11.1 cm^2 or a throat diameter of 37.6 mm (about 40 mm). The lowest throat diameter in Table 4.3 is 60 mm, corresponding to a maximum gas demand of 30 Nm^3/hr. It is thus obvious that the 5 H.P. system as envisaged in the Indian context does not come in the range of 'time-tested' gasifier designs. A further complication is that the size of wood chips used was 50 mm x 40 mm x 15 mm, which would choke the throat if the throat is of the same size. This led the way for trial operations with throat diameters of 50 and 55 mm [26], and a diameter of 55 mm was finally selected for the commercial design [27]. A throat diameter of 55 mm, which might be suitable from fuel movement point of view, would however, yield a maximum SGR of 0.42 Nm^3/cm^2 hr for the required maximum demand of 10 Nm^3/hr.

An SGR of 0.42, though permissible, is not desirable from the point of view of tar content in the gases. Lower SGRs have invariably been linked with lower temperatures in the fire box and higher tar contents in the gas. The I.I.T. Delhi group slightly over-estimated the gas demand, and still using the maximum hearth load of 0.9 Nm^3/cm^2-hr, arrived at a throat diameter of 45 mm [12]. The group at I.I.Sc. Bangalore, following the Imbert gasifier design methodically, arrived at the correct throat diameter of 40 mm for their first prototype gasifier [28]. Three more prototypes were subsequently fabricated and tested with throat diameters of 30 and 35 mm, along with other design changes [29]. Parikh et. al. [16] selected a throat diameter of 100 mm for a maximum gas demand of 45 Nm^3/hr, which corresponds to an SGR of 0.57 Nm^3/cm^2 hr, as against the recommended maximum of 0.9 Nm^3/cm^2 hr. Graf [23], recommends a 'relative capacity' of 1200 kg/m^2 hr for single throat designs. Assuming a gas yield of 2.4 Nm^3/kg, the above figure yields a specific gasification rate of 0.288 Nm^3/cm^2 hr, which seems to be too low for satisfactory operation. For a double throat design, he mentions a value of 4200 kg/m^2 hr, which would yield an SGR value of 0.966 Nm^3/cm^2 hr. However, in the example given in [23], a throat area of 110 cm^2 was arrived at for a gas demand of 0.018 Nm^3/sec, yielding an SGR of 0.589 Nm^3/cm^2 hr. None of the publications from SPRERI and I.I.Sc. Bangalore report problems arising out of 'unacceptable' levels of tar in the gas. On the other hand, most of the reports mention problem of choking (and frequent poking) of the throat. SGRs chosen by almost all the throated gasifier designs are well within the upper and lower bounds prescribed by the Gen-gas book and are thus expected to yield relatively clean gases. And yet, the problem of tar had been debated in several forums extensively. Perhaps there was an undue emphasis on the gas quality rather than on other operational problems such as bridging and choking. Summarizing the above discussion, it appears that the prime need for trying out several designs arose from the overriding importance placed on the 5 hp systems in the Indian context. Design of gasifiers for the 5 hp system contained an inherent incompatibility between the practical wood chip sizes and desirable throat diameters. Barring the problem of fuel movement for small gasifiers there is no evidence to suggest that the classical Imbert type gasifiers, if designed according to the empirical data given in Table 4.3, are unsuitable for engine applications.

The throatless gasifiers, developed by SERI and later adopted by the I.I.Sc., Bangalore group with some modifications, seems to overcome the main problem of fuel movement by using larger diameters in the combustion-reduction zone and a large height to diameter ratio. However, using a larger diameter results in an SGR value lower than that recommended for throated designs. Hearth loads as low as 0.05 Nm^3/cm^2 hr are reported by Reed [24]. The I.I.Sc. design has a conical firebox, with the lowest diameter of 80 mm for the 3.7 kW engine use. With an estimated gas demand of 10 Nm^3/hr, the SGR at the lowest cross section is 0.2 Nm^3/cm^2 hr. Unlike the Imbert-type design, no guidelines for selection of SGR have been so far specified for throatless designs. That the throatless designs operate at low SGR values and still produce acceptable quality gases is due to the good insulation provided around the gasifier. Use of fuel other than wood, such as corn cobs, was mentioned as an additional advantage of throatless designs, but it appears that the fuel movement is related not only to gasifier geometry but also to the physical characteristics of the fuel such as bulk density. It has been mentioned [17] that the frequency of shaking the gasifier was more for corn-cobs than for wood (once in every 30 minutes in comparison to once in an hour and half for wood). Arecanut husks posed more serious problems. Thus, it is apparent that fuel movement problems are not yet solved, even with throatless designs.

Discussion so far has centered around small sized gasifiers. The gas production range of Imbert type gasifiers is 30-230 Nm^3/hr, for throat diameters of 60-200 mm. A 100 kW system, for example, would need a producer with a capacity of 240 Nm^3/hr which is at the upper edge of the Imbert gasifier range. Reed [24] mentions that the Imbert design cannot be scaled-up to larger sizes because air enters at the sides and is incapable of penetrating a large diameter fuel bed unless the fuel size is increased proportionally. He also mentions that some efforts to scale the Imbert gasifier to larger sizes have realised a disastrous increase in tar production. However, researchers have met with more success when the fuel size was increased with gasifier size. Billets that were 8 cm in diameter and 15 cm long have been used in large Imbert gasifiers for heating application. The throatless design has been projected as suitable for any power level, but the claim has so far not been substantiated and there would definitely be problems of scaling. For example, if one takes the same SGR value as for 3.7 kW system (0.2 Nm^3/cm^2 hr), the smallest diameter required for a 100 kW system would be 39 cm, whereas for the throated design it would be only 20 cm. It would thus seem that the throated design would be cheaper than throatless design for higher sizes of gasifier. The 100 kW system developed by I.I.Sc. Bangalore uses a gasifier with a 250 mm diameter at the lowest cross section. This corresponds to an SGR of about 0.5 Nm^3/cm^2 hr, which is closer to the Imbert type design. The SERI design used for higher gas throughputs has a hearth load as high as 0.62 Nm^3/cm^2 hr [24]. Thus selection of hearth load for throatless designs seems to be still arbitrary. Parameters for throatless design is shown in fig 4.1 (c). The maximum specific gasification rates (hearth load) is plotted against gas production capacities for Imbert type and throatless designs in fig. 4.2. It can be seen that while the maximum SGR for throated designs varies between 0.8-1.05 Nm^3/cm^2 hr, around the recommended maximum of 0.9 Nm^3/cm^2 hr, no such consistency is observed for throatless designs. It can only be said that the throatless designs are capable of operating at much lower SGRs, the upper limit (dictated perhaps from economic considerations) still being 0.9 Nm^3/cm^2 hr.

4.2 Nozzle area, Air blast velocity etc. :

The area provided for air entry determines the quality of the gas and is a crucial design parameter. The actual

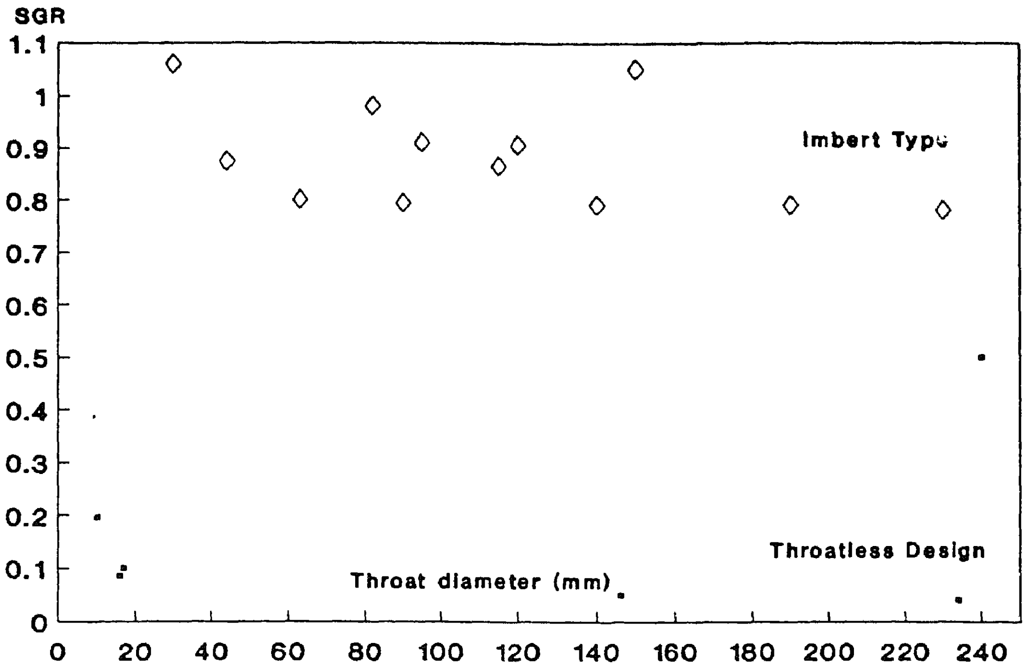


Figure 4.2 : Maximum specific gasification rates for Imbert type and throatless designs.

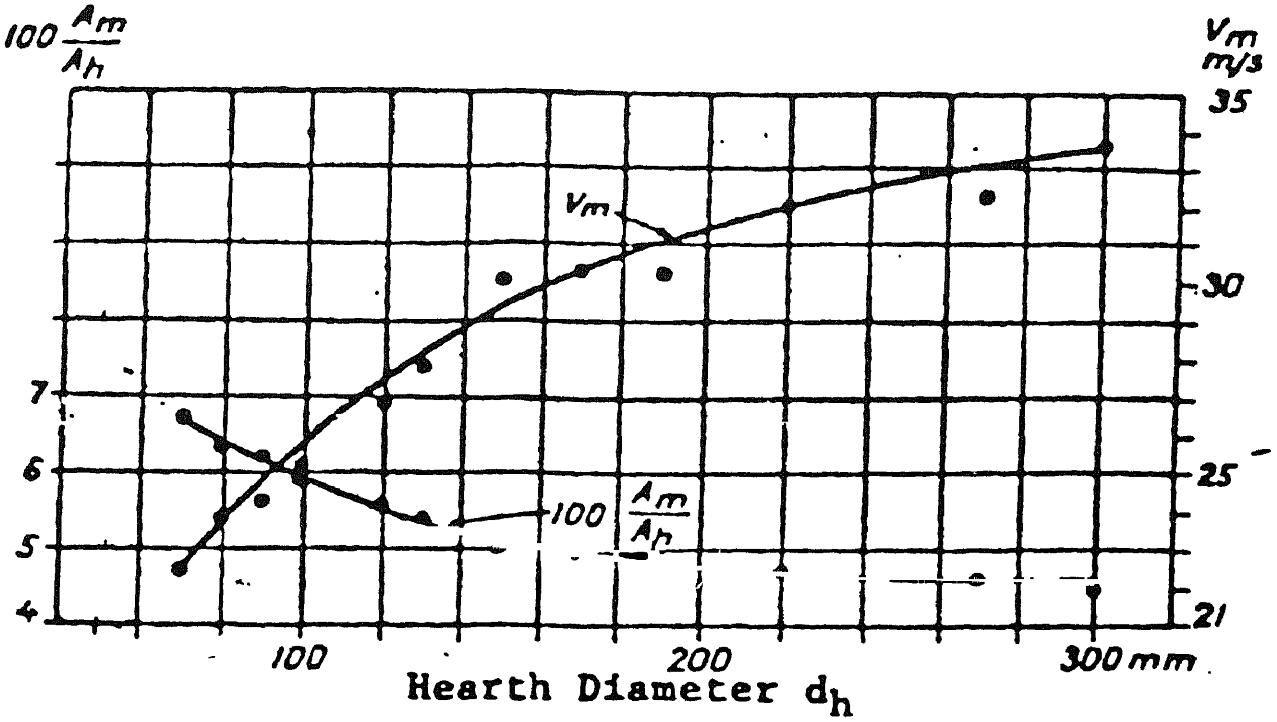


Figure 4.3 : Variation of the parameter 100 (A_m/A_h) and V_m with hearth diameter.

amount of air sucked through the nozzle during operation depends upon several factors such as the engine suction, pressure drop across various components in the gasifier, total number of nozzles etc. However, the 'theoretical' air blast velocity is related to the total nozzle area. The air to gas ratio, obtained from equilibrium considerations is about 0.6. Thus, if the gas demand is G Nm^3/hr, the air demand would be 0.6 G Nm^3/hr. The theoretical air blast velocity Vm (m/s) is then given by

$$Vm = \frac{0.6\ G}{3600\ Am}$$

where, Am is the total nozzle area in m^2. For an assumed maximum hearth load of 0.9 Nm^3/cm^2 hr, the maximum air blast velocity is given by

$$Vm,\ max = \frac{150}{100\ (Am/A_h)}$$

where, A_h is the throat area.

The variation of the parameter 100 (A_m/A_h) with hearth diameter for Imbert gasifiers and for Swedish gas generators is given in the Gengas book. A larger variation has been noted in the graph. However, another graph, drawn up on the basis of a proposal from Hesselman Motor Corp. Ltd., is also given in the same book, and has been widely used for design purposes. This graph, showing both the parameters 100 (A_m/A_h) and V_m, with hearth diameter is reproduced in fig. 4.3. It has been mentioned that the graph is valid for four-cycle engines with many cylinders and that for slow, two cycle engines with few cylinders, it is desirable to increase the nozzle diameter so much that V_m is decreased to approximately 2/3rds of the values given for the four cycle engines. It has also been stated that a decrease of V_m by using larger nozzles causes a decrease of the maximum temperature in the hearth and that a well insulated hearth function satisfactorily with a lower V_m than an uninsulated hearth.

The value of 100 (A_m/A_h) for the GM 55 gasifier of SPRERI works out to 16, corresponding to a V_m of 5.26 m/s. In comparison with the values recommended in the Gengas book, the nozzle area is too large and the air blast velocity is too small for this design. However, the SPRERI values are in close agreement with the curve given for 'Imbert sport', extrapolated to a throat diameter of 55 mm. The throat is not insulated and with low V_m value, low hearth temperatures and high tar contents are to be expected for this design. The I.I.Sc. throated design has a value of about 12 for 100 (A_m/A_h) and 12.7 m/s for V_m. The prototypes seemed to be performing quite well before I.I.Sc. embarked upon the throatless design. The I.I.T. Delhi design used a V_m value of 19-22 m/s and arrived at a lower value for air nozzle area (3 x 6 mm nozzle, 100 $A_m/A_h = 5.33$). The design air blast velocity was high, and resulted in the formation of ash lumps signifying high localised temperatures. Increasing the nozzle diameter to 9 mm (100 $(A_m/A_h) = 12$; $V_m = 12.7$ m/s), eliminated the problem of lumps. It is illustrative to note that, by trial and error, the I.I.T. group arrived at the same values for 100 A_m/A_h and V_m as the I.I.Sc. group. The trial and error part could probably have been avoided if the design procedure recommended in the Gengas book was followed rigorously. For designing a 45 Nm^3/hr gasifier, Parikh et. al. [16] used Nordenswan's data to arrive at a hearth diameter of 100 mm and nozzle area of 3.39 cm^2 (3 x 12 mm dia nozzles). These values yield a 100 (Am/Ah) of 4.3 and V_m of 22.1 m/s. (The authors mention a V_m value of 14.4 m/s, which seems to have been obtained using a lower air-gas ratio of 0.39:1). The corresponding values recommended in the Gengas book are 6 and 26 m/s values respectively, which are not very different from the values obtained following Nordenswan's data. Graf [23] has given curves showing variation of air velocity with hearth diameter which are slightly different from the curve given in the Gengas book, the velocities being lower in the former. The air velocity curves given in the literature are based on the opinion that there should be a greater air velocity in the nozzles of larger hearths so that the air stream has a greater capacity to penetrate towards the hearth centre. According to the Gengas book, whether the change of air velocity in this way is really desirable or necessary has never been satisfactorily investigated. This statement holds good even today. A large number of variations in the mode of air inlet can be found in the literature. There are no firm recommendations on the number of tuyers to be used, once the total nozzle area is obtained. Horizontal tuyers. slanting tuyers, central air inlets, tangential air inlets have been used by different workers and there has so far been no firm basis for selecting one or the other mode of air inlet. In the throatless design developed at SERI, all the air for combustion-reduction reactions is supplied through the top of the gasifier which is open. Thus, the value of (A_m/A_h) is equal to unity. With such enhanced area for air supply, the air flow rate will be decided by the pressure drop across the fuel bed. The pressure drop across packed beds is dependent upon the fuel size, diameter of the reactor, void fraction and height of the bed. Reed [24] does not give any guidelines for selecting these parameters for throatless gasifiers. Values for parameters such as length of flaming pyrolysis zone and length of reacting char zone, have, however been obtained from theoretical considerations, but the total length of these zones is much less than the length of the gasifier. The I.I.Sc. Bangalore group arrived at a length/diameter ratio of about 8 for throatless gasifiers. The reasons for the selection of the L/D ratio have not been elaborated but the requirement of a large pressure drop across the bed can be one of the reasons. The I.I.Sc. design is different from SERI design as far as the mode of air admission is concerned. In the former, an air inlet nozzle of 19 mm dia has been provided in addition to the air already entering the gasifier from the top, presumably to arrest the slow upward migration of the combustion zone. It has also been stated that 65-70% of the air needed came through the air nozzle and the rest from the top. It is not clear whether the 65-70% figure is obtained from measurements or from calculations. For the 3.7 kW system, with the assumed 70% air going through the nozzle, the air inlet velocity comes to about 4.1 m/s, which is much lower than that recommended for throated designs. For the 100 kW design, however, 6 horizontal nozzles of 20 mm I.D have been provided. If the proportion of air supply is same as that for the 3.7 kW gasifier, the air inlet velocity can be calculated as approximately 15 m/s, which is closer to that recommended for throated designs. It is thus apparent that, as in the case of selection of gasifier diameter, the selection of air nozzles area is also not governed by any design rule as far as the throatless design is concerned.

Parameters such as height of air inlet above throat, diameter of nozzle ring etc. which are needed for the design of throated gasifiers can be obtained from graphs provided in the Gengas book, but are not needed for the throatless design.

4.3 **Gas residence time :**

This is an important parameter which decides the extent of reactions occuring in the gasifier, especially the reduction reactions. For the Imbert type design, the dimensions of the reaction cone, viz, the hearth diameter, nozzle ring diameter and the height of air inlet above hearth, are related to each other in such a way that the reaction time is constant. For the family of curves given in the Gengas book, a residence time of 0.11 sec. (at STP) is obtained for all generators, not accounting for volume occupied by fuel. For the realistic condition of 1200^{o}C and 40% void volume, the residence time of gases in the combustion zone works out to be about 0.01 sec for the maximum hearth load of 0.9 Nm^3/cm^2-hr. For the reduction region, the Gengas book stipulates that the part of the hearth below the narrowest section should be made as a truncated cone, with height d_h and the opening diameter 2.5 d_h. With these measurements, and for the maximum SGR of 0.9 Nm^3/cm^2-hr, the gas residence time below the hearth can be obtained as equal to 0.0013 d_h (sec), with d_h expressed in cm. For the range of Imbert gasifiers, d_h varies from 7 cm to 30 cm and hence the residence time varies from about 0.1 sec to 0.4 sec, assuming 0^{o}C and 100% void. For an average temperature of 1000^{o}C in the reduction zone and a void volume of 40%, the residence time varies from 0.008-0.03 sec. Thus, for the Imbert type designs, the total residence time of gases in the combustion zone varies form 0.018-0.04 sec for the complete range.

The first three prototypes of the I.I.Sc. gasifiers (Imbert type) had a reduction zone volume of 320 cm^3 corresponding to a residence time of 0.025 sec and the fourth prototype had a reduction zone volume of 250 cm^3 and a residence time of 0.02 sec. The details of computing (void fraction, temperature etc.) have not been mentioned but it can be seen that these values are close to residence times recommended for Imbert type designs. The GM-55 design of SPRERI had a reduction cone volume of 881.6cm^3 corresponding to a residence time of 0.03 sec (1000°C, 50% voids). Including the volume of combustion cone, the total residence time will be about 0.05 sec, which is twice that of I.I.Sc., designs. The I.I.T, Delhi designed a 'transit time' of 7.7 ms, which was defined as the quotient of the fire length and the air velocity in the tuyers. The fire length was defined as the vertical distance between the air tuyers and the bottom of the reduction zone. From the dimensions given [12], the volumes of the combustion and reduction zones can be calculated as 430 and 1000 cm^3 respectively. For the assumed gas flow rate 14.52 Nm^3/hr, the residence time can be computed as 0.35 sec at 0°C and 100% void and 0.038 sec at 1000°C and 50% void. The I.I.T., Bombay throated design for 45 Nm^3/hr does not seem to take the residence times into account, but from the dimensions given, the volume of combustion cone works out to 1578 cm^3 and, assuming a similar volume for reduction, the residence time (50% void, 1000°C) can be obtained as 0.03 sec.

The throatless design of SERI seems to rely on a 'char residence' time rather than a gas residence time. A char reaction time of 100 sec has been mentioned for these designs. Translating this to gas residence time is not straight forward, but assuming i) a char to biomass flow rate ratio of 0.5:1, ii) a yield of 2.5 Nm^3 per kg of biomass, and iii) a bulk density of 600 kg/m^3 for char, the gas residence time (0^oC, 100% void) is obtained as 0.033 sec, which is about an order of magnitude lower than the value recommended for throated designs. The throatless design of I.I.Sc., however, has an approximate residence time of 0.03 sec for a gas temperature of 1000^oC and a void fraction of 50%.

From the above discussion, it can be seen that the gas residence time computed at 50% voids and 1000^oC is in the range of 0.02-0.05 sec. for practical gasifiers. This range is in very good agreement with the values recommended for Imbert type gasifiers. This is not a coincidence, but a direct result of application of whatever design rules provided in the Gen gas book. It is, however, desirable to have a theoretical basis for selection of this parameter. Based on kinetic considerations, Gumz [30] had recommended a gas residence time of 0.5 sec, which does not seem to have been followed in the design of practical gasifiers. Considering that the composition of gas obtained in most gasifier designs is not very different from equilibrium composition, it appears that a residence time of 0.5 sec is not really required. Also, residence times as calculated above assume that all the volume in the combustion-reduction zone is available for reaction, or in other words, that there are no stagnation points. In actual gasifiers non-ideal conditions do exist, leading to a residence time distribution (RTD).

The only study which attempted to obtain RTD in downdraft gasifiers is due to Groeneveld [31]. As maximizing the dwell time of pyrolysis gases in the high temperature zone is the key to produce gases with the lowest tar content, more research effort should be directed in studying residence time distribution.

An 'ash residence time' is some times used by researchers to highlight problems due to clinker formation, but such a residence time has not been used in the designing of gasifiers.

4.4 Grate, Ash removal systems etc. :

Several designs of grate have been employed for gasifiers. A fixed flat grate is one of the simplest designs and is widely used. Some designs of shakeing grates, used for Imbert designs have also been mentioned in the literature. For high ash fuels, a slowly rotating grate that has a milling effect on the clinker is usually employed. Two designs, the star grate and a rotating eccentric grate, come under this category. Vertical and inclined step grates have also been used in designs such as the cross draft gasifier. Details of design of grate, are not, however provided in the literature.

The major use of biomass gasifiers during the 2nd world war was for automobiles, which, because of the vibrations and jerks inherent in the system, did not warrant a separate ash removal system. Almost all stationary applications, whether for biomass gasification or for coal gasification, had to resort to some sort of continuous ash removal mechanism. The SPRERI design tried to utilise the engine vibrations for shaking off the ash as well as to aid fuel movement within the gasifier. The efficacy of this method for high ash fuels is uncertain. As most of the gasifier designs in India are for wood, which has low ash contents (less than 3%), the ash removal problem has not been highlighted so far. Kaupp [5] experimented with several designs of ash removal systems for rice hulls and concluded that rotating systems which crush the clinker are best suited for high ash fuels. Throatless designs of I.I.Sc. have not employed an ash removal system, but these designs have also not been tried extensively for high ash fuels and hence the ash removal capability of these cannot be ascertained. In fact, Reed [24] mentions that the foremost question about the stratified downdraft gasifier design concerns char and ash removal. The rotating eccentric grate or other similar device, though capable of removing ash continuously, throws up some design issues. It can remove ash only at a fixed rate, and hence variation in ash formation rate, which is a direct consequence of variation in fuel consumption can lead to accumulation of ash and lump formation. Hence some norms have to be laid regarding the speed of rotation, which has to be correlated to the ash removal rate. The other problems related to the rotating grate are the added complexity and the increased need of maintenance. It is apparent that a simple,yet effective design for continuous removal of ash is still to emerge.

4.5 Choice of materials of construction :

The choice of materials and sheet thickness has a direct bearing on the life of the system. Compromises made on quality and quantity of materials of construction have almost invariably resulted in material failure. The fire box in the classical Imbert design is subjected to high temperatures and a reducing atmosphere and hence is prone to failures. The throat in these designs was replaceable cast component. Almost all Indian designs of the throated type used stainless steel (SS 310) for nozzles and fire box, following the design of Damour [25]. In one of the earlier prototypes developed at I.I.Sc., it was found that after about 100 hrs. of operation the throat made of AISI-304 stainless steel had enlarged from 30 mm diameter to an elongated hole of 40 mm. There were also cracks close to the air entry point. These problems were rectified by changing the design and final the prototypes went through about 400 hrs. of testing. The I.I.Sc. group claims that the main advantage of the throatless design is that it overcomes the problems associated with the life of the throat as mentioned above. But the absence of throat does not eliminate the harsh environment inside the fire box, and ironically the field experience with the throatless gasifiers does bring out the problems of material failure. It is stated [28] that the air nozzle cracks up and burns out near the welded joint at the inner wall after 300 hrs. of operation in a few places and after 900 hrs. in others. Details of materials and sheet thickness have not been provided by the I.I.Sc. group and it is not clearly known if the cracks were due to improper welding or inadequate sheet thickness. Kaupp, on the other hand, mentions that during three years of testing under no slagging conditions, the UCD laboratory gas producer has never shown any damage to the tuyers and the choke plate. Experience with various designs does not conclusively prove the superiority of one design over the other as far as life is concerned. In the absence of a systematic study relating the life of the fire box to material type and gauge, it is difficult to make concrete recommendations regarding these. Use of refractory materials such as fire clay or ceramics either directly or as lining has sometimes been recommended, but the experience with such designs is quite limited. In choosing materials and gauges, recourse could have been taken to existing knowledge of metallurgical practices in furnaces, ovens etc. but this approach does not seem to be prevalent in gasifier design.

4.6 Design of associated subsystems :

Claims of production of 'tar-free' gas apart, no practical gasifier system could ever dispense with the associated cooling and cleaning sybsystems for utilising the gas in I.C. engines. This 'conditioning' of gas is necessitated by the fact that engine quality gas has some upper tolerance limits for temperature, dust, tar and moisture. Surprisingly there are not many post-war studies that have concentrated on fixing these upper limits. It would appear that such studies are not difficult to perform -

one has to systematically vary these parameters artificially in the gas and observe effects such as engine wear, clogging of valves, power reduction etc. Contaminating the gas arbitrarily to a desired level of tar similar to that produced in actual gas producers might be difficult, but no such attempts have been made. Studies made during 1930-50 showed [4] that with a dust concentration of upto 10 mg/Nm^3 the engine wear was of the same order as that obtained with gasoline, but beyond that amount it increased rapidly, being up to five times as great when the concentration reached 50 mg/Nm^3. No such studies are available for Diesel engines, for example, operated in the rural areas of India. It is known that several rural areas in India can be dusty, with dust concentration of 200 mg/m^3 or more in the air and yet diesel pumps are widely used. Upper limits of 100 mg/Nm^3 for total tar and 50 mg/Nm^3 for particulates had been recommended for Indian conditions [16], but the basis for such a recommendation is not well established, especially for the Indian conditions. Reed [24] states that the quantity of condensable organics (tar) should be reduced to 10 mg/Nm^3 before admitting into the engine. Particles larger than 10um must be removed to a level below 10 mg/Nm^3. Design of the conditioning equipment should logically depend on i) the quality of raw gas and ii) the desirable quality of conditioned gas. The latter being fixed, the parameters of raw gas to be known for designing the cleaning-cooling equipment are flow rate, temperature, dust content, tar content, moisture content, particle size distribution of the dust, solubility of contaminants in water etc. One should therefore be making systematic measurements of these parameters over wide operating conditions before designing the gas conditioning equipment, but such an approach is seldom followed. The most common practice is to install some of the several known devices such as the cyclone, wet scrubber, filter etc., usually on an adhoc basis. Methods of designing such equipment and arriving at correct dimensions are elaborated in literature [4, 24, 32], but if the input parameters for the design are based on assumptions rather than actual measurements, the performance of the equipment can be quite off the mark.

The earlier gas cleanup unit of the SPRERI gasifier consisted of a cyclone, a packed bed wet scrubber, a dry filter and a security filter. Coke was used as the packing material in the wet scrubber and cotton waste was used in the dry filter for removing moisture. In a later design, the cyclone was replaced with a venturi scrubber and coke was replaced with pebbles. Use of filter to remove moisture from the gas 'after' scrubbing is not usually mentioned in gasifier literature. The operation manual for the SPRERI gasifier states that the cotton waste should be replaced after every 50 hrs. of operation. The gas after wet scrubbing is usually saturated with water vapour and it is not possible to remove any moisture from the stream without substantial cooling. The fact that the cotton waste was getting quite wet after 50 hrs. of operation indicates the possibility of heavy water entrainment in the gas due to faulty design of the scrubber. The I.I.T., Delhi team used a wetted wall cyclone and a drum-filter. Only the temperature drops and pressure drops across these devices are reported but the efficacy of these devices in cleaning the gas has not been established. The I.I.Sc., Bangalore group used a cyclone, a dry cooler and a fabric filter in that order for all the gasifiers, though the designs underwent changes from time to time. The tar content of the gas after cleaning was in the range of 50-120 ppm (1 ppm is approximately equal to 1 mg/Nm^3) and the particulate content was in the range of 80-150 ppm, according to measurements at I.I.Sc. Later measurements at I.I.T. Bombay showed different results. In one set of studies, the tar content was 40-120 ppm and the particulate content was 50-300 ppm. In the second set of studies, the tar content was 150-180 ppm and the dust content was 460-1000 ppm. The discrepancy in the data could not be explained. In later units of the I.I.Sc. gasifier systems, a cold cyclone was introduced into the circuit and a packed bed sand filter was provided in addition to the coir pith filter. This arrangement seems to have reduced the combined tar and particulate level to less than 30 ppm. The I.I.Sc. throatless design operates at a low specific gasification rate and low air blast velocities as noted earlier. Also, the group claims that due to upturning of gases at the bottom, some dust will be collected in the gasifier itself. All these factors combined together should indeed have resulted in a low particulate level in the gas. The measurements contradict this supposition and a satisfactory explanation of the phenomenon is warranted. The I.I.T., Bombay design which has tangential air inlets in the gasifier, uses a wet cyclone for cooling and cleaning and no other filtering devices. The tar level in the gases for this design varied from 60-80 mg/Nm^3 and the particulate level varied from 50-200 mg/Nm^3. The high dust level has been attributed to the addition of swirl component to the already high gas velocities in the reduction zone.

In all the cases mentioned above, tar and particulate concentrations in the raw gas have not been reported. Hence the supremacy of one method over the other, or the efficiency of the devices used cannot be established with any certainty.

The total pressure drop across the cooling cleaning train has a profound effect on the system performance. It should be remembered that air for combustion and gas are sucked into the engine through different pipes during regular operation. The suction created is dependent mainly on the rpm of the engine, and is almost constant for all loads. The proportion of gas and air flow rates adjusts according to the pressure drops in the respective lines. If the increase of pressure drop across gasifier and associated train is very steep, the rate of flow of gases into the engine will not be adequate, leading to a drop in diesel replacement. This phenomenon has been observed both in the I.I.Sc. and I.I.T., Bombay systems. This only points out the need to approach the design of subsystem components with care and precision.

The selection of piping, valves etc. is also critical. The pipe diameters should be chosen so as to keep the pressure drops low, at the same time taking into consideration the gas velocity requirements for conveying various contaminants to their proper points of removal [24].

4.7 Overall system design :

A gasifier installation for pumping or power generation needs components like blowers, cutters etc. For initial start up and ignition, a blower is needed. The earlier SPRERI design used a hand operated blower which is quite laborious and inconvenient. The Ankur gasifier design uses the engine exhaust as an ejector for creating the initial suction. In this method the CO in the producer gas is vented directly into atmosphere, which can be hazardous. Manual cutting of wood into small pieces was recommended for SPRERI gasifiers, which is again laborious and undesirable. The I.I.Sc. design provides for a 0.75 kW electric saw for cutting wood into smaller pieces. Diesel pumpsets are used by farmers mainly because of uncertainties in the supply of electricity. In such a situation, it is ironical that a gasifier system, which is essentially a diesel saving device, should need electricity for sustained operation.

Many researchers decry the fact that gasifier and the associated subsystem design is more art than technology, but conscious and sustained effort is lacking on the part of the same researchers to raise the gasifier 'craft' to the level of technology.

5. DESIGN OF THE PRESENT GASIFIER SYSTEM - FIRST PROTOTYPE

In the proposal stage itself, the main problem of gasification of biomass was identified as that due to fuel movement. The design of the gasifier should ensure a smooth vertical flow of the fuel which is necessary for unhindered gas production. Apart from this, the other problem areas identified were i) design of continuous ash removal system ii) processing of biomass so as to ensure uniformity in physical properties such as bulk density, size, shape etc. and iii) design of simple and effective systems for cooling and cleaning of raw gas. This section deals with the design of the first prototype gasifier unit.

5.1 Calculation of gas requirements :

The gasifier was intended to be coupled to a 5 hp diesel engine with the following specifications.

rpm : 1500
Bore dia : 80 mm
Stroke : 110 mm
type : four stroke
Diesel consumption : 1000 g/hr

The amount of gas-air mixture sucked into the engine cylinder can be calculated as 24.88 m^3/hr. For an assumed diesel replacement of 85%, the diesel consumption in dual fuel mode would be 150g/hr. The air required for combustion of diesel is in the ratio of 1:20 (diesel:air) on weight basis. Hence the quantity of air required for combustion of diesel would be 3000 g/hr. The density of air at $0^{o}C$ and 1 atm is given as 1.2928 kg/m^3 [32]. The air density at $30^{o}C$ is obtained as 1.1648 kg/m^3. Hence the air required for diesel combustion is calculated to be 2.575 m^3/hr at 30°C. The rest of the volumetric flow, consisting of producer gas and air, is then obtained as 22.3 m^3/hr. For complete combustion, the producer gas-air mixture should be in the proportion of 1:1 by volume. Hence the gas required is 11.15 m^3/hr or about 10 Nm^3/hr. This value is slightly lower compared to the gas requirements calculated by other workers by different methods [12, 26, 28] for a 5 hp gasifier system. It should be mentioned that the experimentally obtained gas flow rate [17] for 3.5 kW and 85% diesel replacement is about 8 Nm^3/hr. It should also be mentioned that the primary energy flow for dual fuel operation with 0.15 kg/hr of diesel and 10 Nm^3/hr of gas is actually higher (14.7 kW) compared to that for 100% diesel operation (12.5 kW). It can thus be seen that even with reduced engine efficiency for dual fuel operation, the gas demand can not exceed 10 Nm^3/hr.

5.2 Design of fire box :

A conventional, Imbert type gasifier, with a maximum hearth load of 0.9 Nm^3/cm^2-hr, will require a throat diameter of 37.6 mm. As observed in Chapter 4, this diameter is outside the range of classical Imbert designs and can cause serious problems of fuel flow. The throatless designs, which are capable of operating at lower specific gasification rates, would thus be more suitable for use in conjunction with a 5 hp engine. The problem, however, is that of selecting a proper diameter for the fire box. The experience of most of the earlier workers indicated that an increase in throat diameter resulted in lower fire box temperatures and hence higher tar contents in the gas or production of a gas which does not burn at all. A preliminary analysis of heat losses from the fire box showed that for an Imbert design with a throat diameter of 60 mm, the combined convective and radiative heat losses from the curved surface of the hearth zone are of the order of 3-4 kW. If the heat losses from a larger diameter fire box can be brought to within these limits, say, by insulation, it should be possible to obtain the requisite temperatures necessary for cracking of tars. Calculations also showed that, depending on k value of the insulation and thickness, the heat losses can be reduced to 0.3-0.4 kW for an average fire box temperature of 1000°C and a diameter of 200 mm. This diameter of the fire box, being eminently suitable from fuel movement point of view, has finally been selected. The specific gasification rate corresponding to this diameter and a gas demand of 10 Nm^3/hr works out to 0.03 Nm^3/cm^2-hr, a value which has not been attained so far for downdraft gasifiers including throatless designs.

The length of the fire box (from centre of air nozzles to grate) was kept at 20 cm, corresponding to a gas residence time of 0.24 sec, assuming a temperature of 1000°C and a bed void fraction of 50%. Provision had been, however, made to reduce the reactor volume and hence the residence time by a simple mechanism by which the length between the air inlet and grate could be adjusted. This was done mainly due to the uncertainty involved in fuel properties. A high ash biomass fuel would require a low ash-residence time so as to prevent clinker formation and a mechanism for controlling this parameter is highly desirable.

Selection of the diameter and number of air nozzles was difficult as the present design did not conform to existing models. The gasifier was required to accept several biomass residues and hence obtaining the air requirements by means of equilibrium computations was also thought to be non-applicable. The amount of air needed was thus obtained simplistically by making a nitrogen balance, assuming that all nitrogen in the gas is coming from air only. Based on the data of Jenkins [13] for various biomass residues, an average concentration of 50% was assumed for nitrogen in the producer gas stream. A material balance on nitrogen yields

$$V_a = V_g \times \frac{\rho_g}{\rho_a} \times \frac{0.5}{0.79} \times \frac{M_a}{M_g}$$

where, V, ρ and M represent volumetric flow in Nm^3/hr, density (at STP) and average molecular weight respectively. Subscripts a and g correspond to air and gas respectively. For $\rho_g = 1.0$ kg/Nm^3, $\rho_a = 1.293$ kg/Nm^3, $M_a = 28.2$ and $M_g = 25.1$, the volume rate of air intake is 5.62 Nm^3/hr. The volumetric rate is 6.23 m^3/hr at 30^oC.

This value was cross checked by a different method of calculation also. Again taking recourse to the data of

Jenkins, an average value of 2.1 Nm^3/kg (biomass) was taken for gas production and a value of 1.5 kg/kg (biomass) was taken for air requirement. For 10 Nm^3/hr of gas, 4.76 kg/hr of air was thus obtained, corresponding to a volumetric rate of 6.13 m^3/hr at 30°C. This value closely agrees with the one calculated above.

The problem now is that of selecting the air blast velocity. Taking cue from earlier studies, a velocity of about 12.5 m/s seemed reasonable. The nozzle area is then directly obtained by dividing the volumetric flow rate by velocity as

$$A_m = \frac{6.23}{3600 \times 12.5} = 0.000138 \text{ m}^2$$

selecting two nozzles, the diameter of each nozzle was obtained as

$$d = \left[\frac{0.000138}{2} \times \frac{4}{\pi}\right]^{\frac{1}{2}}$$

$$= 0.0094 \text{ m.}$$

Obtaining nozzles with 9.4 mm dia is difficult. If a diameter of 10 mm is selected, the air blast velocity would be reduced to 11.0 m/s. The Gengas book, however, recommends lower air velocities for insulated hearths. Hence it was thought that 2 nozzles with 10 mm dia would be adequate for the gasifier.

5.3 Other details of the main gasifier unit :

For convenience in effecting modifications whenever necessary, the gasifier was made in three separate parts, viz 1) the fuel hopper ii) the fire-box (combustion-reduction zone) and iii) the ash box. The hopper was designed so as to hold about 27 kg of biomass with a bulk density of 175 kg/m^3. With an assumed consumption of 4.5 kg/hr, the gasifier can hold enough material for continuous operation upto 6 hrs. The ash collector has a diameter of 0.6m and a height of 0.3m. Air-tight doors have been provided for loading fuel, removing ash and for having access to the firebox outer side. The fire box is insulated with glass wool mats sheathed by a G.I. outer cover. The gas passes through the grate and through the annulus formed by the outer wall of the gasifier and the G.I. sheath for insulation and exits through the middle portion of the gasifier. 3mm thick (10 gauge) sheet was used for the fabrication of the entire gasifier. The material of construction is SS310 for firebox and air nozzles, and MS for the rest.

No particular criterion was applied in the selection of cone angle for the hopper, mainly because of the uncertainly regarding the fuel to be used. Reed [24] mentions that good fuel hopper design calls for a cone angle that is double the 'dugout angle of repose', which is defined as the steepest angle (from the horizontal) formed by the sides of a pile of fuel when material is removed from the bottom of the pile. Graf [23] recommends that the angle should be equal to the angle of repose, generally measured by filling a large tube with the fuel and then lifting the tube allowing the fuel to form a pile and noting the angle from the horizontal to the sides of the pile. The first prototype had an angle of 42 ^{o} from the horizontal. It was later observed that this particular angle was not suitable for fuels with high bulk density and several methods of agitation of fuel bed had to be tried.

A drawing of the main gasifier unit of the first prototype is shown in Fig. 5.1.

5.4 Design of the ash removal system :

It has been noted in earlier sections that the gasifier systems used for automobile applications were self purging owing to the very nature of application and that the majority of stationary applications, especially those that used biomass and/or high ash fuels required some kind of continuous ash removal systems. The earlier Jyothi gasifier systems used a vibrating frame structure deriving the vibratory motion from the diesel engine itself. This method, which was primarily meant for facilitating the fuel movement did not completely solve the objective, but seems to be satisfactory as far as ash removal is concerned, but the point was never highlighted. In fact the whole question of ash removal is not prominent in Indian gasifier R & D, mainly because of the emphasis on wood which has a low ash content (1-3%). As can be seen from Table 3.2 and from gasifier literature [24], several biomass residues have both high ash

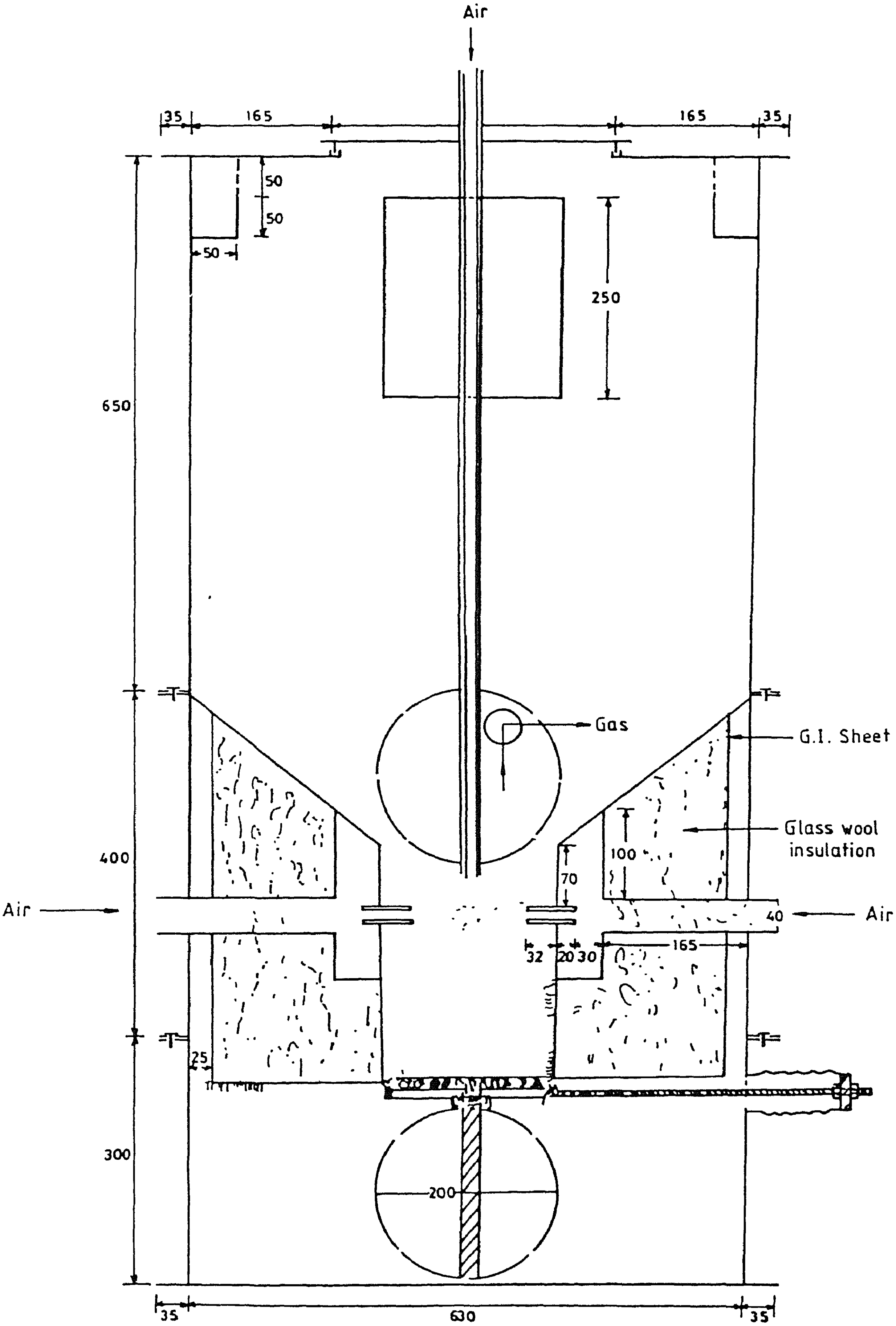


Figure 5.1 : The main-gasifier unit of the first prototype.

contents and low ash melting points, a combination which leads to slagging. In fact, the degree of slagging had been described as 'severe' for fuels containing 7% or more of ash. As the present project aimed at using several biomass residues, it was imperative that an effective ash removal system be developed. The rotating grate system was not considered as it was thought to be complicated and hence justified only for larger installations. There was also the problem of designing air-tight joints needed for the rotary system. Drawing upon the P.I's earlier experience on bellow-coupled hermetical sealing systems [35], a vibrating-grate ash removal system has been designed. The view of the system is shown in fig. 5.2. The grate, made of an MS ring and MS rods, is firmly attached to a bottom MS ring which rests on a grate holder. The bottom ring is connected to a vibrating arm, the other end of which is coupled to a metallic end plug. A rubber bellow joins this end plug and a pipe of suitable diameter welded onto the ash holder of the gasifier. The two ends of the bellow are firmly secured onto the metallic pipes by fasteners so as to provide an air-tight hermetric sealing. The free, vibrating end of the bellow is coupled to a reciprocating device powered by a small motor. A locally available reciprocating piston pump, with the pump part removed, served as the reciprocating device. The speed of oscillation could be adjusted by suitable selection of the pulleys connecting the shafts of the motor and the reciprocating device. After several trials, a frequency of 194 cycles/sec was found to be satisfactory for effective ash

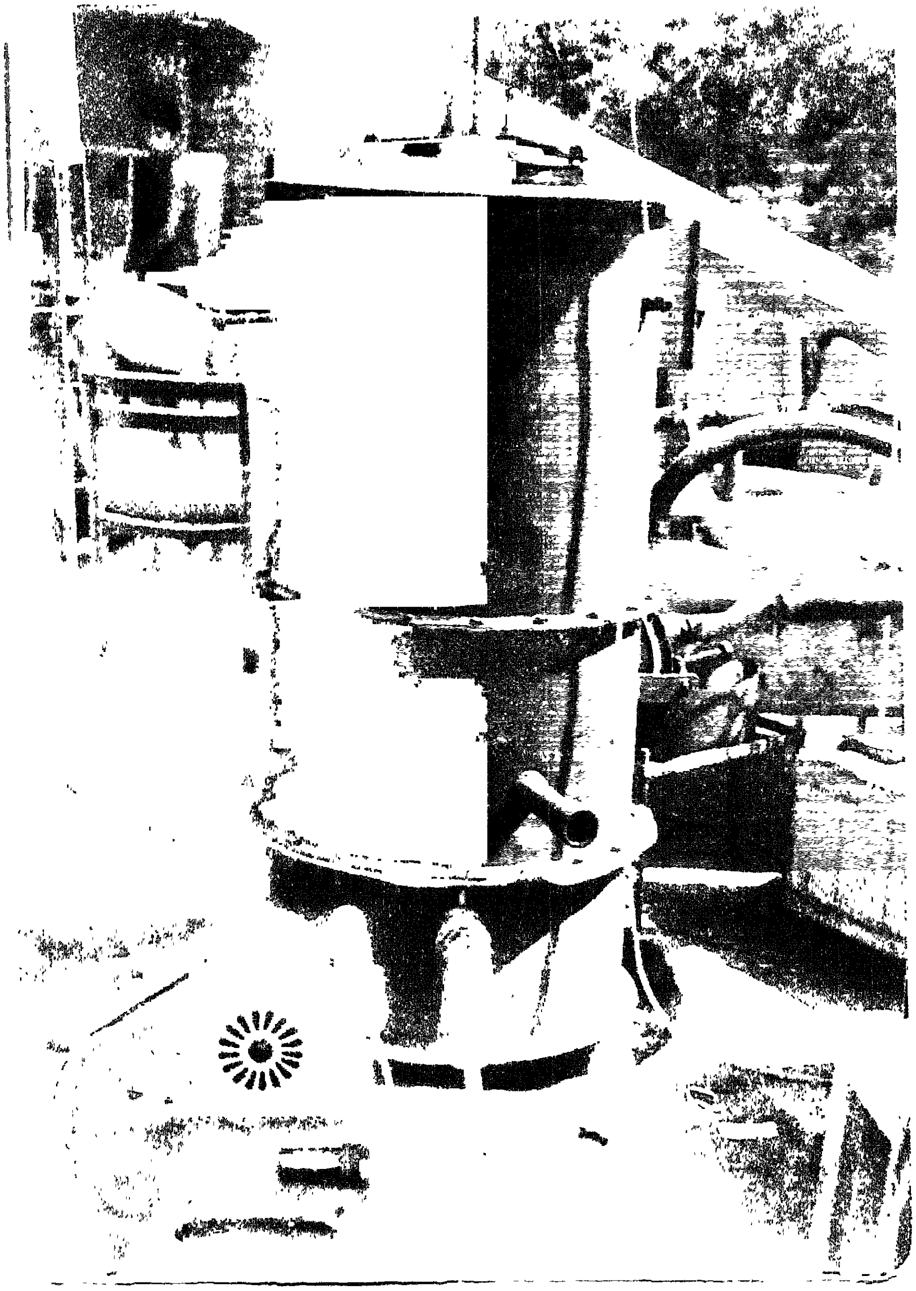


Figure 5.2 : Vibrating-grate ash removal system.

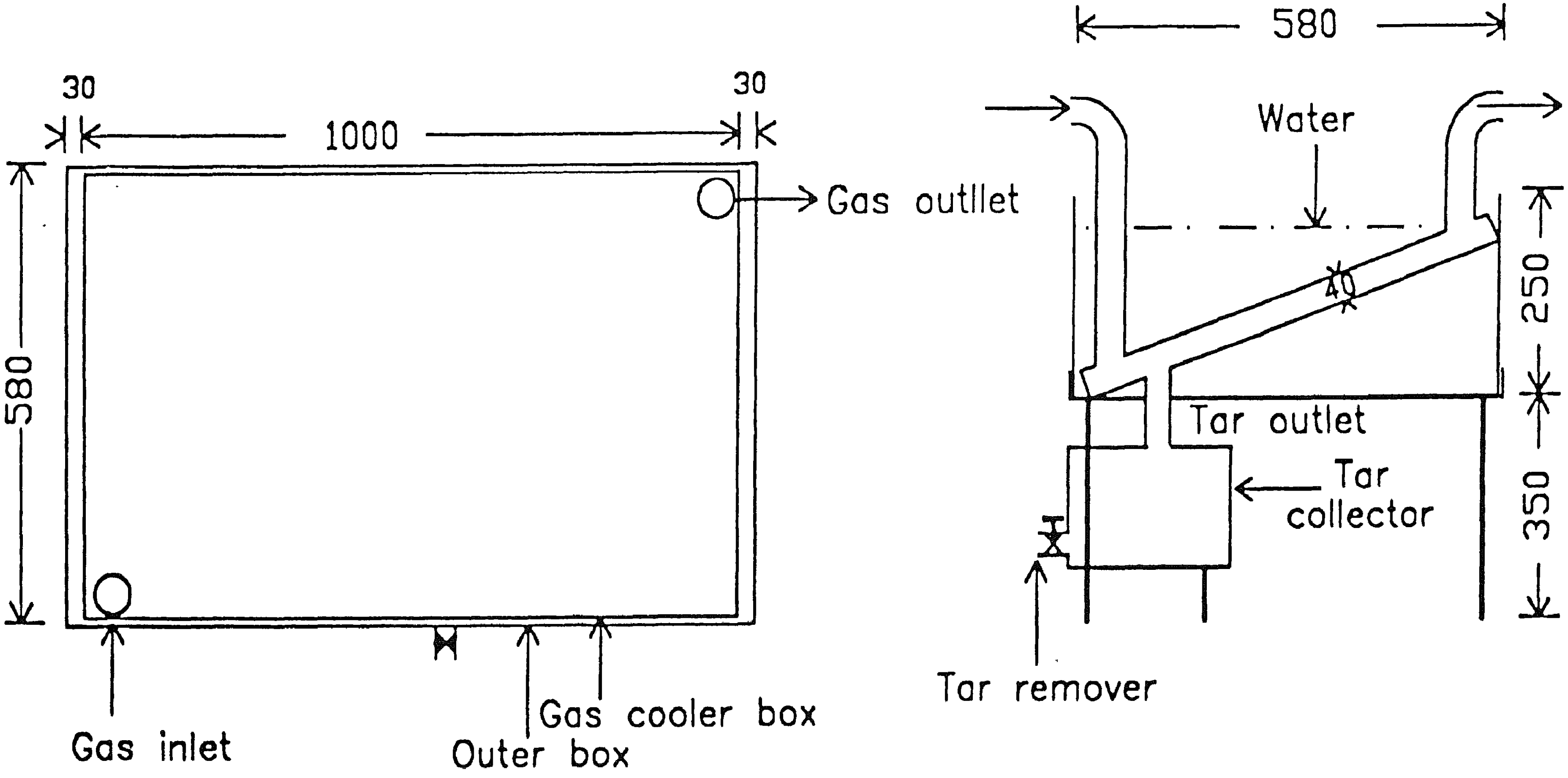
removal. The bellows last for a few hundred hours of operation and the exact life time could not be established, which is a function of frequency, half-angle of deflection and temperature. Metallic (SS) bellows were considered, but were found to be very expensive. It was found that even a large diameter hose pipe can be used in place of the bellows.

5.5 Design of the gas conditioning system :

The gas conditioning system for the first prototype consisted of a gas cooler cum tar separator and a dust filter. As conventional scrubbers add significant amount of water in the form of mist which has to be later removed from the gas stream, use of some kind of dry cooler had been envisaged at the proposal stage itself. The first cooler developed was a simple rectangular box kept in an inclined position in a trough of water. The tar and moisture collected in the box could be removed from time to time through a valve provided at the bottom of the box. The dimensions of the box were calculated from the desired rate of removal of heat from the gas. Kaupp [4] has given an empirical correlation for finding out the amount of water to be removed from the gas. Using the correlation, a value of 0.5 kg/hr was obtained as the water removal rate, corresponding to a latent heat removal rate of 270 kcal/hr. The sensible heat removal rate for cooling the producer gas from 200°C to 50°C was obtained as 360 kcal/hr, giving a total heat removal ratio of 630 kcal/hr. The heat transfer area needed to achieve this rate of cooling is obtained by the equation

$$630 = UA\ (LMTD)$$

where, U is the overall heat transfer coefficient, A is the area and LMTD is the log mean temperature difference. Assuming the temperature of the water outside the cooler box to be 45^{o}C, and taking a U-value of 25 w/m^{2}C [33], A is calculated as 0.67m^2. Providing for uncertainties in the assumptions of heat transfer coefficients, flow non idealisties etc. an area of 1.0 m^2 was taken. Hence a rectangular box with a length of 1m, width of 0.5m and depth of 0.04m has been selected. It has to be noted that the heat transferred to the cold water bath would ultimately be lost to the atmosphere by convection, radiation and evaporation. The convective, radiative and evaporative losses can be estimated as [34], 132, 83 and 1022 w/m^2 respectively for a tray of water exposed to ambient conditions assuming a relative humidity of 60% and an ambient temperature of 30^{o}. The area needed to discard 630 kcal/hr is then calculated as 0.59 m^2. The actual dimensions of the tray were selected as 1.06 x 0.58 x 0.25, giving a top surface area for water as 0.615m^2, which is more than adequate. The drawings for the box-type gas cooler cum tar separator are shown in fig. 5.3 and a photograph of the gas cooler system is shown in fig. 5.4. The performance of this cooler cum tar separator was quite satisfactory, as detailed in chapter 8, but as the rectangular box was completely closed, there was no access to the inside of the box, which is desirable in the long run. A



Top view

Side view

Figure 5.3 : Gas cooler cum tar separator

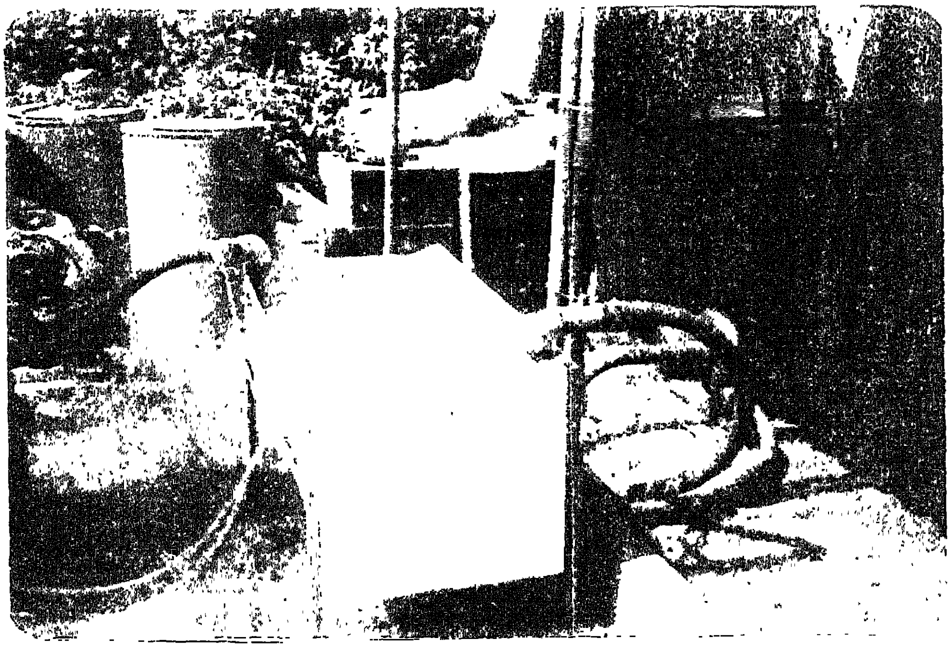


Figure 5.4 : Photograph of the gas cooler system

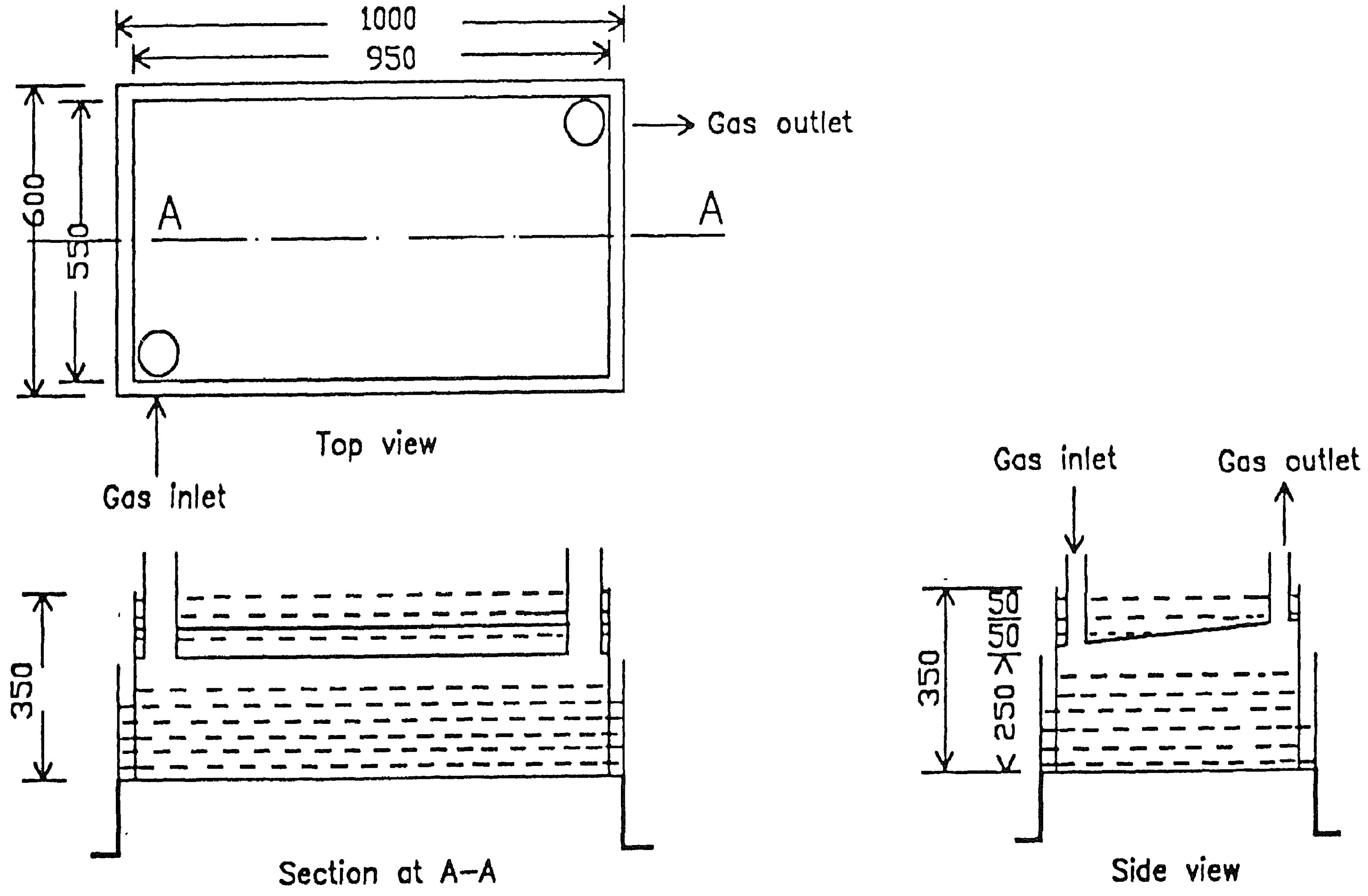


Figure 5.5 : Modified design of the cooler cum tar separator

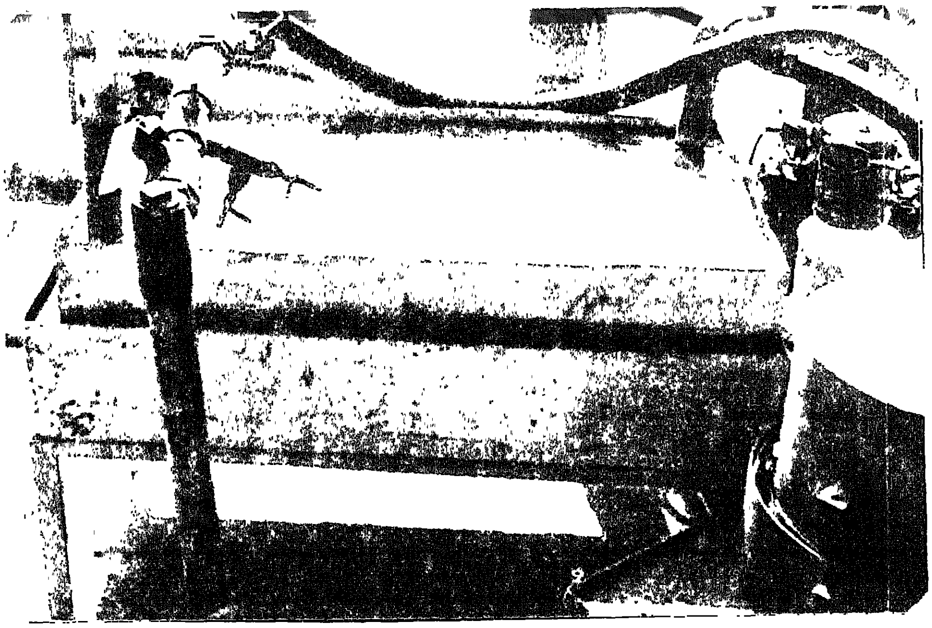


Figure 5.6 : Photograph of the modified gas cooler cum tar seperator.

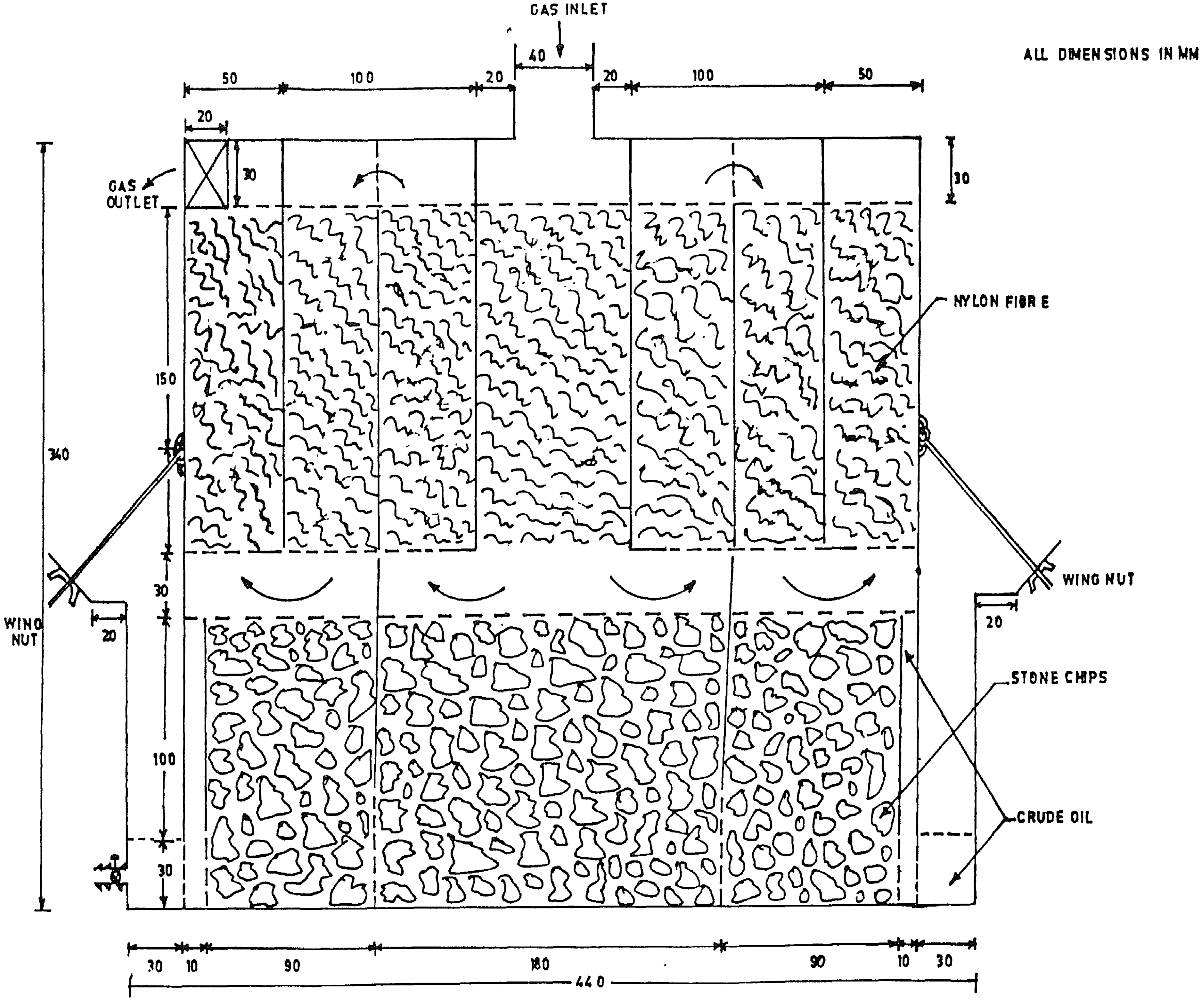


Figure 5.7 : Schematic diagram of the dust filter.

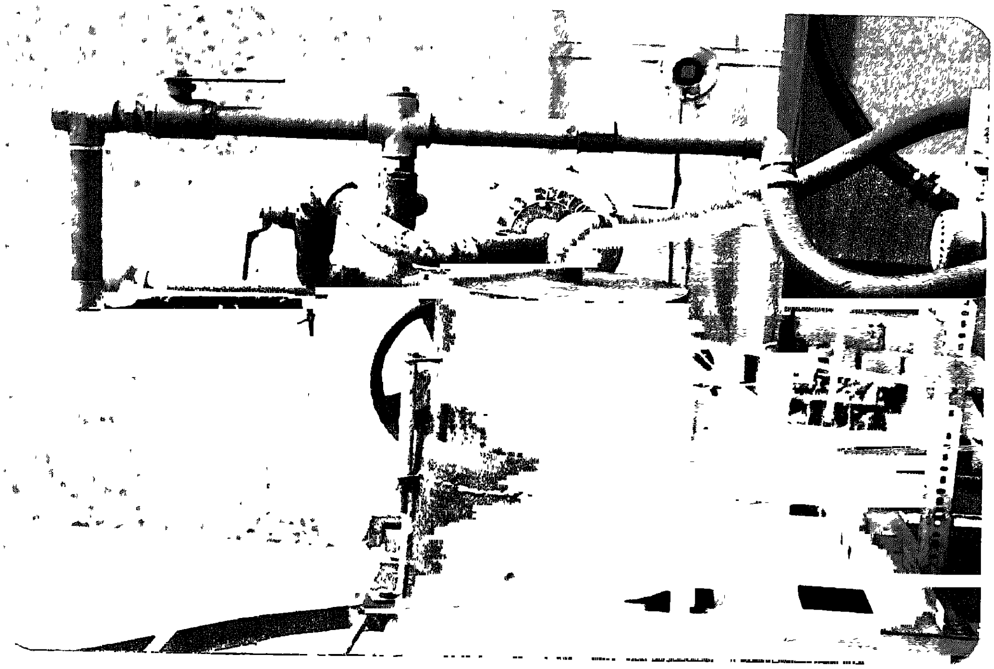


Figure 5.8 : Photograph of the dust filter.

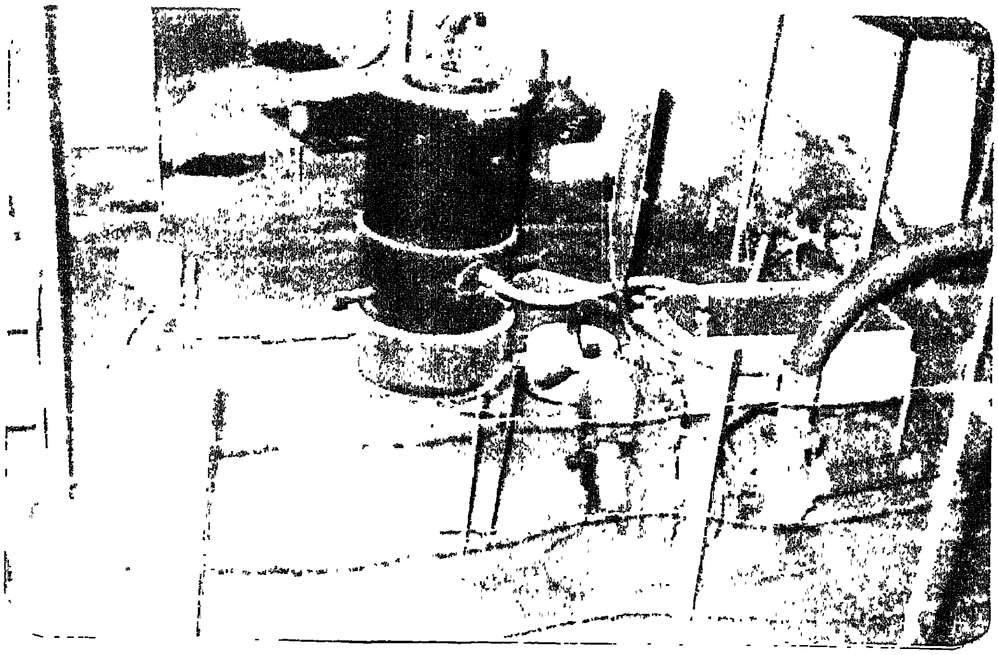


Figure 5.9 : View of the complete system.

modified design of the cooler cum tar separator as shown in fig. 5.5, was conceived at a later stage in the project. The modified version consists of two rectangular G.I. trays, one used as a trough and the other used as a gas holder which is placed inside the trough filled with water. The upper portion of the gas holder has a sloping surface and has projections on all four sides so as to form a tray in which water is filled. The raw gas passes through the narrow channel formed by the surface of water in the trough on the one side and the cool, metal surface of the tray on the other. Tar and water condensed on the cool, sloping surface of the upper tray trickle down into the water bed. The cooler is a passive device, requiring no attention for many days of operation. The principle of operation is same as that of the earlier design and the dimensions are about the same. The entire cooler was made with MS and then galvanised before installation. The upper tray can be removed any time for cleaning if necessary. A photograph of the modified cooler cum tar separator is shown in fig. 5.6.

The design of the dust filter is similar to that of the cooler. It consists of a bottom cylindrical vessel, open from top, filled with oil, and a top, inverted cylinder, containing nylon meshes. The gas is made to pass through several annular spaces, and above the oil surface, before exiting tangentially from the dust filter. Stone chips were placed in the oil bath so as to reduce the quantity of oil. The height of the oil bath is selected in such a way as to allow a suction head of 10 cm oil. MS was used as the material of construction. The schematic diagram of the dust filter is shown in fig. 5.7 and a photograph of the same is shown in fig. 5.8.

A Kirloskar 5 hp dual fuel pumpset obtained locally, was coupled to the gasifier system through a carburettor for better mixing of producer gas and air. A seperate loop had been provided for flaring the gas. An electric blower was used for initial ignition and flaring of the gas. Suitable ports had been provided at various points in the system for pressure measurement, gas sampling etc. A view of the complete system installation appears in fig. 5.9.

6. BRIQUETTING OF BIOMASS

The earliest attempts in this project for briquetting were concentrated on coal dust. Mixtures of coal dust and cattledung in various proportions were made into balls manually and sun-dried, following the age old process of making dungcakes. A ratio of 1:9 by weight (dung : coal powder) was found to be suitable for making briquettes. The briquettes had a calorific value of 3700 kcal/kg and an ash content of 48%. The ash melting point was above 1000°C. Tests in the gasifier showed that burning gas was obtained, but sustainable operation could not be achieved as the briquettes were disintegrating easily inside the gasifier. Besides, this process was laborious and the quality of briquettes was inconsistent and hence a search was launched for procuring/developing a suitable low cost machine for briquetting.

Letters were written to several agencies involved in briquetting of biomass in May 1986, soon after the project started. The list of such agencies/manufacturers is shown in Table 6.1.

Table 6.1 : Partial list of briquetting manufacturers contacted

1.	School of Applied Research	Sangli
2.	Biosolar Pvt. Ltd.	New Delhi
3.	Fire implements	Madras
4.	Ion Exchange (India) Ltd.	Bombay
5.	Ameteep M/c tools Pvt. Ltd.	New Delhi
6.	Talwar Brothers Pvt. Ltd.	Calcutta
7.	Biomass Energy Systems	Madras
8.	Alternative Energy Sources	Pondicherry
9.	Desai Coal Company	Kolhapur
10.	INCOR	Visakhapatnam
11.	National Small Scale Industries Inst.	New Delhi
12.	Nimbkar Agricultural Res. Inst.	Phalton
13.	M/s. La-Tech Fuels Pvt. Ltd.	Chandigarh
14.	Bharat Industrial Corporation	Calcutta
15.	Post-Harvest Technology Centre	Jabalpur
16.	National Productivity Centre	New Delhi
17.	The Indian Sugar & General Engg. Corp.	Yamunanagar

Of these, La-Tech Fuels Pvt. Ltd., Ion Exchange (India) Ltd., and Talwar Brothers (Pvt.) Ltd. informed that they have discontinued activities in briquetting due to various reasons. Quotations for briquetting plants were received from Ameteep, NSCI and ISGEC. There was no response from the rest of the manufacturers/agencies. The literature received from the manufacturers pertained to the so called 'binderless' technology of briquetting biomass, in which the biomass is subjected to a very high pressure (1000-1200 kg/cm^2) in a piston driven press. This technology is based on the process developed by Fred Haussmann in Switzerland, in which the lignin present in the biomass becomes 'fluidised' under the action of pressure and forms a very strong 'outer sheath' for the briquettes. All the briquetting presses have outputs in the range of 500-3000 kg/hr and need shaft powers in the range of 22-110 kW. The costs are Rs. 3.5 lakhs upward. The total budget of the project being Rs. 5.17 lakhs, procuring any of these briquetting machines was out of question. However, the team was interested in studying the suitability of these briquettes for gasification. Ameteep informed that their plants are in operation at M/s. Punjab Energy Devices Ltd., Malerkotla and at M/s. Harish Agform Fuels Pvt. Ltd., Rudrapur. However, these companies could not supply briquettes in the small quantities required. A visit to the briquetting plant of ISGEC at Yamunanagar resulted in procurement or rice husk briquettes in sufficient quantity. These briquettes were found to be quite suitable for gasification as will be described in later sections.

However, a continuous supply of the briquettes on a regular basis could not be arranged.

At this juncture, the team came to know that M/s. Alfred Herbert Co. Ltd., Bangalore has developed a pelletising process for biomass. The process involved pulverising biomass by means of an attritor, and then pelletising by adding binders such as tamarind, effluent sludge, molasses, starch, or carboxy methyl cellulose (CMC). The PI visited the company and had discussions with the personnel. The cost of the system (more than Rs. 6 Lakhs) was beyond the reach of the group but the company agreed to supply samples of the pellets for trials in the gasifier. The samples however, could not be supplied by the company owing to several reasons including a prolonged strike in the Company.

The team also came to know regarding the availability of coal briquettes for domestic consumption in Ghaziabad, and could locate a small scale, diesel driven (5 HP), coal briquetting plant. The process of producing these briquettes consisted of mixing various amounts of clay, molasses etc. to coal dust and feeding the mixture manually into a rotating drum type briquetting machine shown in fig. 6.1. The briquettes, which had a high bulk density and a high ash content, were tried in the gasifier. The experiment was not successful as the briquettes could not be ignited at all. The team also tried to make briquettes on the machine,

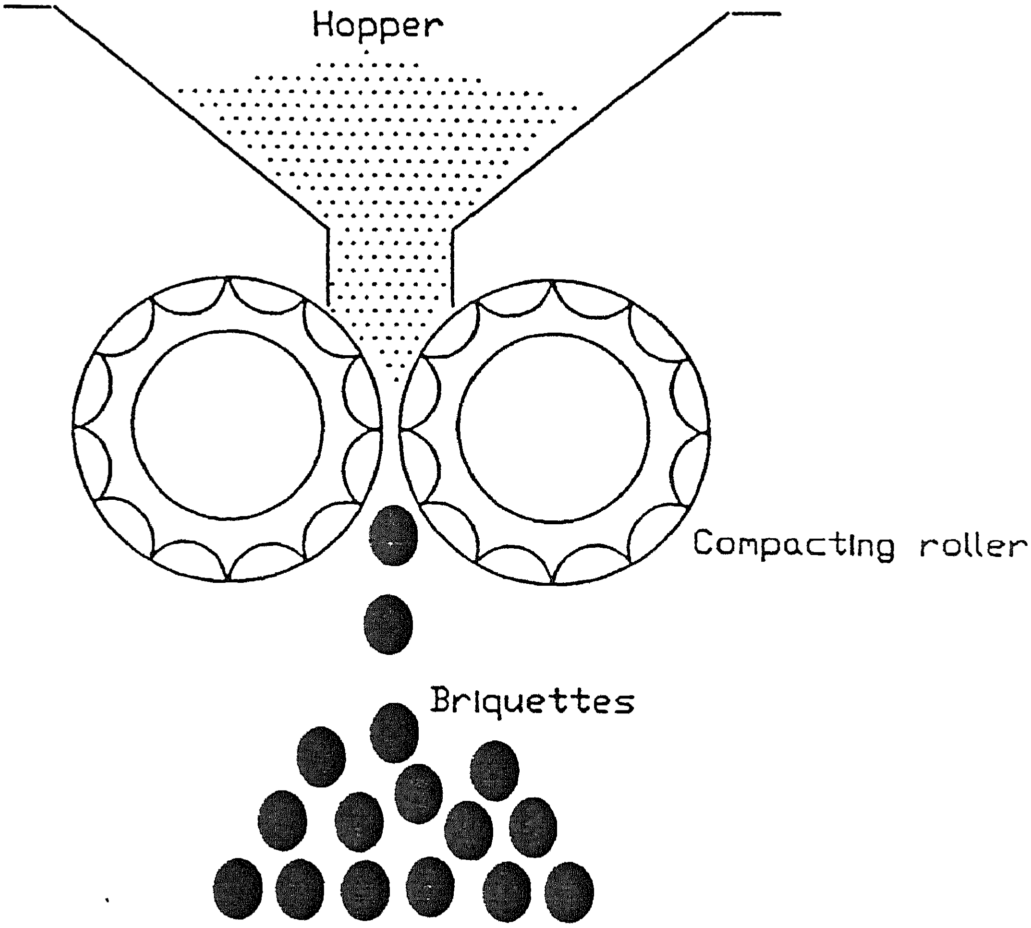


Figure 6.1 : Schematic diagram of a coal briquetting machine.

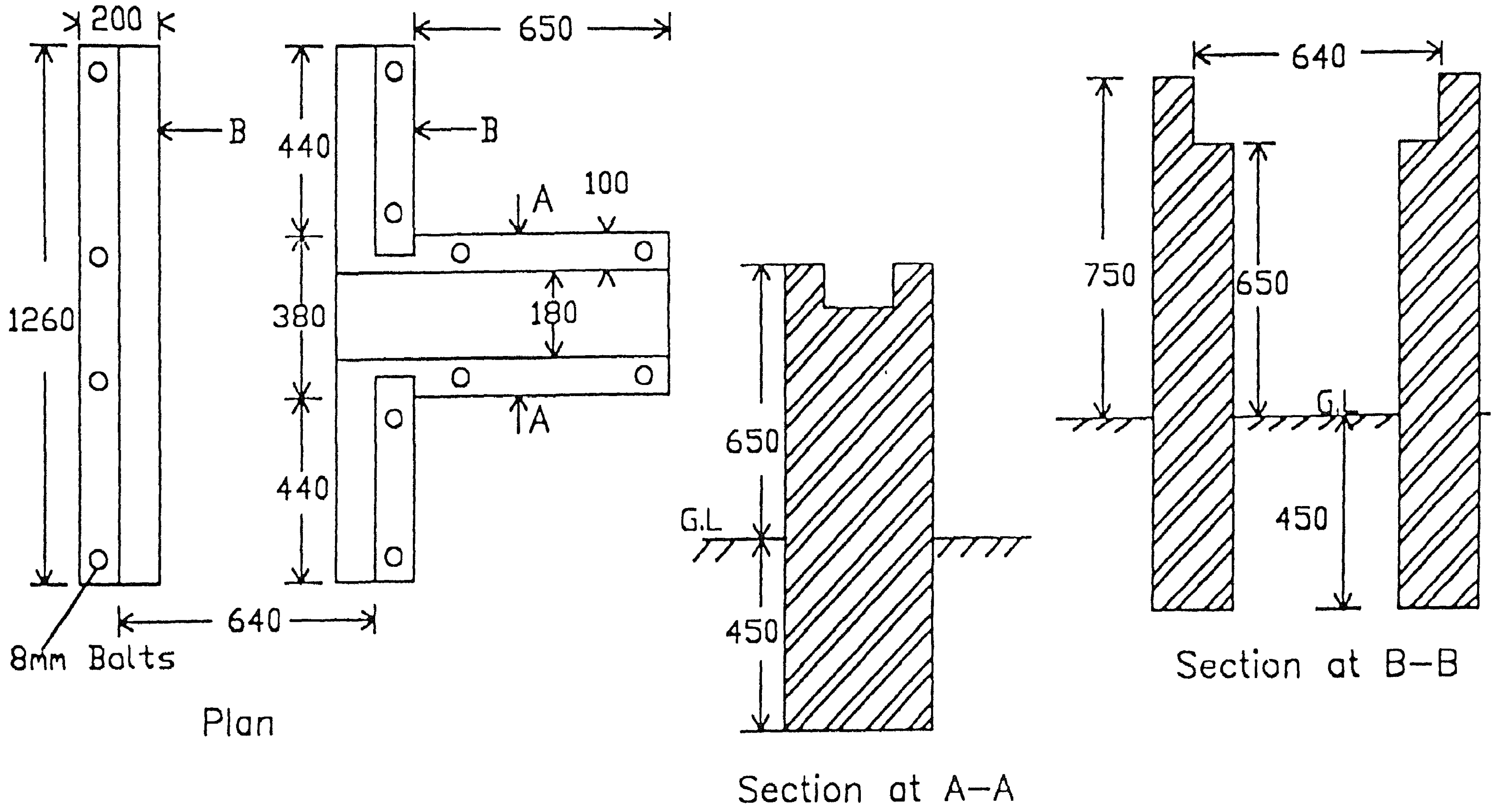
with the kind co-operation of the plant owner. The biomass combinations tried were i) sawdust + dung ii) sawdust + dung + molasses + clay iii) rice husk + dung and iv) rice husk + dung + molasses + clay in various proportions. After several prolonged trials, it was concluded that this type of machine was not suitable for direct biomass briquetting.

The group came to know that CMPDI (Coal Mining Process Development Institute) branch in Delhi was experimenting with hydraulic, hand-operated briquetting machines. Saw dust was briquetted on trial basis by CMPDI. The team visited CMPDI and had discussions with the concerned official with a view of getting saw dust briquettes for experimentation. The CMPDI, however, could not supply the briquettes.

Efforts of other groups in briquetting biomass, especially those of Central Institute of Agricultural Engineering (CIAE), Bhopal and of School of Applied Research, Sangli, were known to the present team for some time and it was decided to consult these groups. A tour was undertaken by two of the team members in early March 1988 to Bhopal. The members met Mr. P.K. Srivastava and Dr. R.C. Maheshwari of CIAE and held discussions with them. CIAE purchased a briquetting machine from Sangli and developed its own version also. The Sangli machine was being fabricated by M/s. Indudyog in Okhla, New Delhi. The machine developed by CIAE was a screw-extruder type, and was primarily meant for briquetting coal dust. The machine was being manufactued in

Indore. The team visited Indore, and obtained quotations for the same, and was informed that the machine can also be obtained from Chandigarh. Upon return to Delhi, M/s. Indudyog were contacted and some sample briquettes of saw dust were obtained. These briquettes were, however found to be unsuitable for gasification as they were disintegrating easily in the gasifier. An order was then placed for the extruding type briquetting machine from M/s. Punjab Engineering Works, Chandigarh, and the machine was procured and installed at TERI for trials. The machine, powered by a 5 hp electric motor, is a slow speed (100-150 rpm) screw extruder, meant for briquetting coal dust with the help of binders such as clay, molasses etc. in suitable proportions. Literature available on briquetting and pelletization indicated that essentially four parameters, viz. i) particle size ii) characteristic of the binder iii) pressure applied and iv) temperature decide the quality of the briquettes. Lower particle size, higher pressure and higher temperature are desirable, but the extruding type machine was not capable of developing higher pressures, as the size of the gap between the worm and the cylinder was large and material was found to be flowing back under unfavourable conditions. As the particle size of biomass was found to be quite important, a pulverizing machine of local make was procured in order to prepare a fine powder from dried biomass. The pulverizer, a hammer mill type, was also powered by a 5 hp electrical motor. The power ratings of both the pulveriser and briquetting machine are thus ideally suitable for the low capacity gasifier envisaged in the project. As binders such as molasses would be difficult to obtain in rural areas (and would be expensive also) and as addition of clay was not desirable due to its clinker-formation tendency, choice of a suitable binder became a little difficult. Experiments showed that cattle dung, effluent slurry from biogas plants and soaked waste papers were all suitable binders for mixing with pulverised biomass. Several minor changes had also to be made in the briquetting machine for use with pulverised biomass. The foundation drawings for the briquetting machine, motor etc. are shown in fig. 6.2. A photograph of the complete briquetting system is shown in fig. 6.3.

After several trials, briquettes were successfully made from i) saw dust ii) groundnut shells iii) mustard stalks iv) bajra stalks v) coir pith and vi) char or coal dust. The briquettes obtained are cylindrical in shape, with about 2.5 cm dia and 7.5 cm long, and are found to be quite suitable for gasification. Properties such as bulk density, volatile matters, ash content etc. of briquettes made from some biomass materials are shown in Table 6.2. Figure 6.4 shows samples of briquettes made from different biomass materials. The briquettes, though not of high bulk density, do not disintegrate easily in the gasifier. Results of



Plan

Section at A–A

Section at B–B

Figure 6.2 : Foundation drawings for the briquetting machine

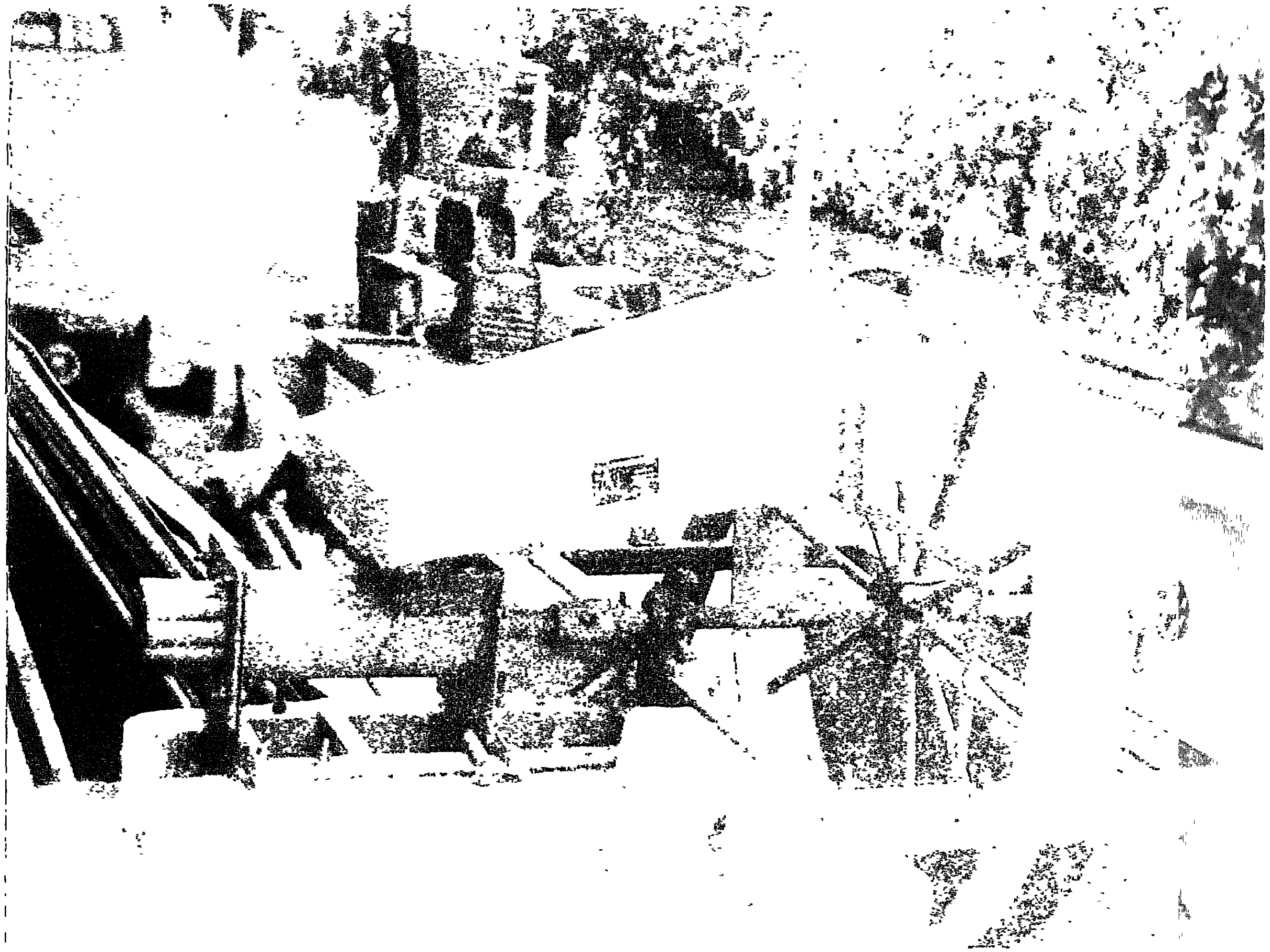


Figure 6.3 : Photograph of the complete briquetting system.

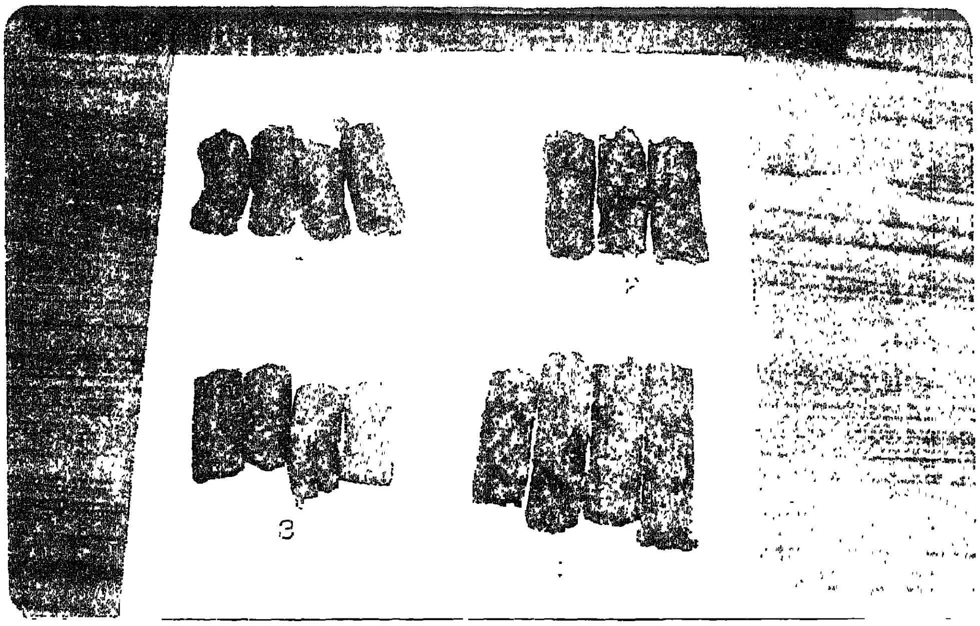


Figure 6.4 : Samples of briquettes made from different biomass materials.

1. Coir pith briquettes
2. Corn stalk briquettes
3. Sawdust briquettes
4. Bajra stalk briquettes

utilising these briquettes in the gasifier are described in section 8. The electricity consumption for making briquettes (including pulverisation) was of the order of 0.1 kWh/kg. The rate of production depended on the type of biomass, particle size, proportion of biomass to binder and moisture content. Exhaustive experimentation on briquetting 'per se' could not be carried out due to lack of time and resources.

Table 6.2 : Properties of biomass briquettes produced in the screw-extruder with biogas plant effluent slurry as binder.

Briquetted Material	True density (kg/cu.m)	Bulk density (kg/cu.m)	Moisture content (%)	Volatile matter (%)	Ash (%)	Fixed carbon (%)
Saw Dust	273 ± 17	252 ± 1	3.2	63.0	18.9	14.9
Bajra stalk	297 ± 13	250 ± 1	3.5	62.6	15.4	18.5
Mustard stalk	378 ± 13	198 ± 1	3.7	70.0	12.3	14.0
Coir pith	254 ± 14	228 ± 1	4.3	58.3	19.2	18.2

It should be pointed out that the need for adhering to the low powered briquetting system is peculiar to this project. A recent survey of briquetting technology [36] shows that there are certain empirical correlations between the power requirements and throughput of the machine for biomass briquetting. One particular correlation, valid both for piston-type and extruding-type briquetting machines is given by the equation

$$P\ (\mathrm{kW}) = 0.58 \times q^{2/3}$$

where, q is in kg/h.

For an output of 100 kg/hr, which appears to be the lower limit for motor driven briquetting machines, the power required is calculated as 12.5 kW from the above equation, which is much higher than the 3.7 kW figure for the briquetting machine used in this project. Use of such low power for briquetting had become feasible only because of the presence of binder, which is not always desirable from cost and availability considerations. Hence, it is apparent that utilisation of binderless technology for briquetting imposes a lower limit of about 40 kW on the prime mover and a corresponding limit on the capacity of gasifier.

7. TESTING OF GAS QUALITY

It had been realised quite early in the project that testing of gas obtained for chemical composition and contaminants is very important in assessing the performance of the gasifier. Several groups working on gasification seem to have ignored this diagnostic aspect as long as satisfactory diesel replacements were obtained. The only place in India where a complete testing of gasifiers can be done is I.I.T. Bombay, but such a centralised facility is not of much use during the stage of development of gasifiers and associated subsystems. Further, the exact methods of testing have not been standardised and made available to researchers in a usable manner yet. This section deals with the work done in the present project on testing of gas quality.

7.1 Measurement of tar, dust and moisture :

A sampling train consisting of a dust collector, tar/moisture collector, flow meter etc. was proposed [37] in the literature. A glass tube packed with suitable material and kept at a high temperature to prevent condensation of tar and moisture in the bed had been suggested for collecting dust. However, clear recommendations regarding the material of the bed, dimensions of the tube, temperature of the bed etc. have not been made. The gas then passes on into a vessel kept at low temperature (about $0^{o}C$) where the tar and moisture would be condensed, after which it goes to a flow meter and a vaccum pump and finally to a burner. Again, the shape and dimensions of the vessel, flow rates of gas to be sampled, and total amount of gas to be drawn, are not clearly defined. A mixture of tar and moisture would condense in the chilled vessel, but methods of separating the two have not been elaborated and standardised in the published literature.

An apparatus fabricated in the early stages of the project for estimation of tar, dust and moisture is based on the above methodology and is shown in fig. 7.1. A glass tube packed with glass wool and kept in the centre of a horizontal tubular furnace was proposed to be used for collecting dust. A cylindrical tube immersed in an ice bath was used for tar and moisture condensation. The shape and size of the tube were selected in such a way that it can be kept in an existing centrifuge for seperation of tar from water. Initial trials on this system were not fruitful as tar condensed in the tube connecting the dust collector to the gasifier and the volume of the chilled vessel was too small to accommodate all the water condensed. In later modifications, the length of the connecting tube was reduced, and a flask instead of a tube was used for collecting tar and moisture. Experiments using a series of secondary tar collectors showed that all the tar and moisture was not getting trapped in the primary tar collector, raising the questions of contacting area and contacting time. A design in which the tar-ladden gas was allowed to impinge upon the chilled walls of the tar collector tangentially (fig 7.2) solved the problem to a large extent, but traces of tar could still be found in the secondary collectors. Final design of

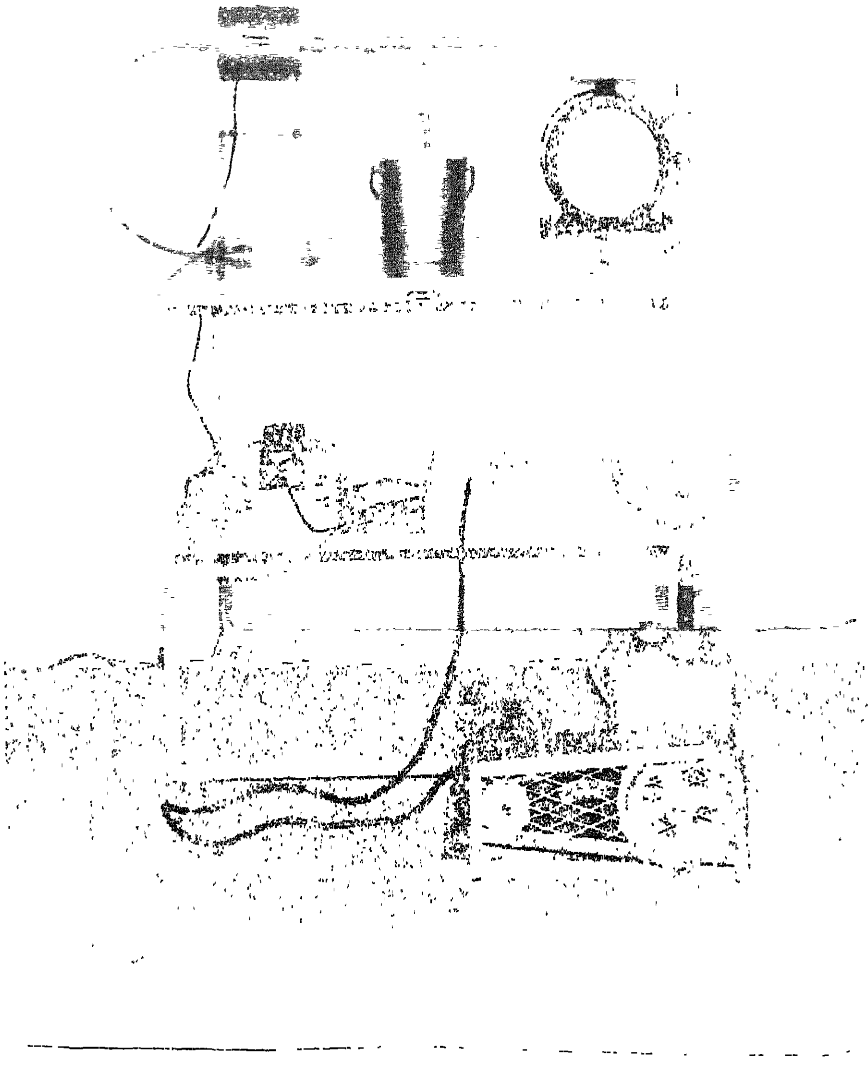


Figure 7.1 : First prototype of the sampling system.

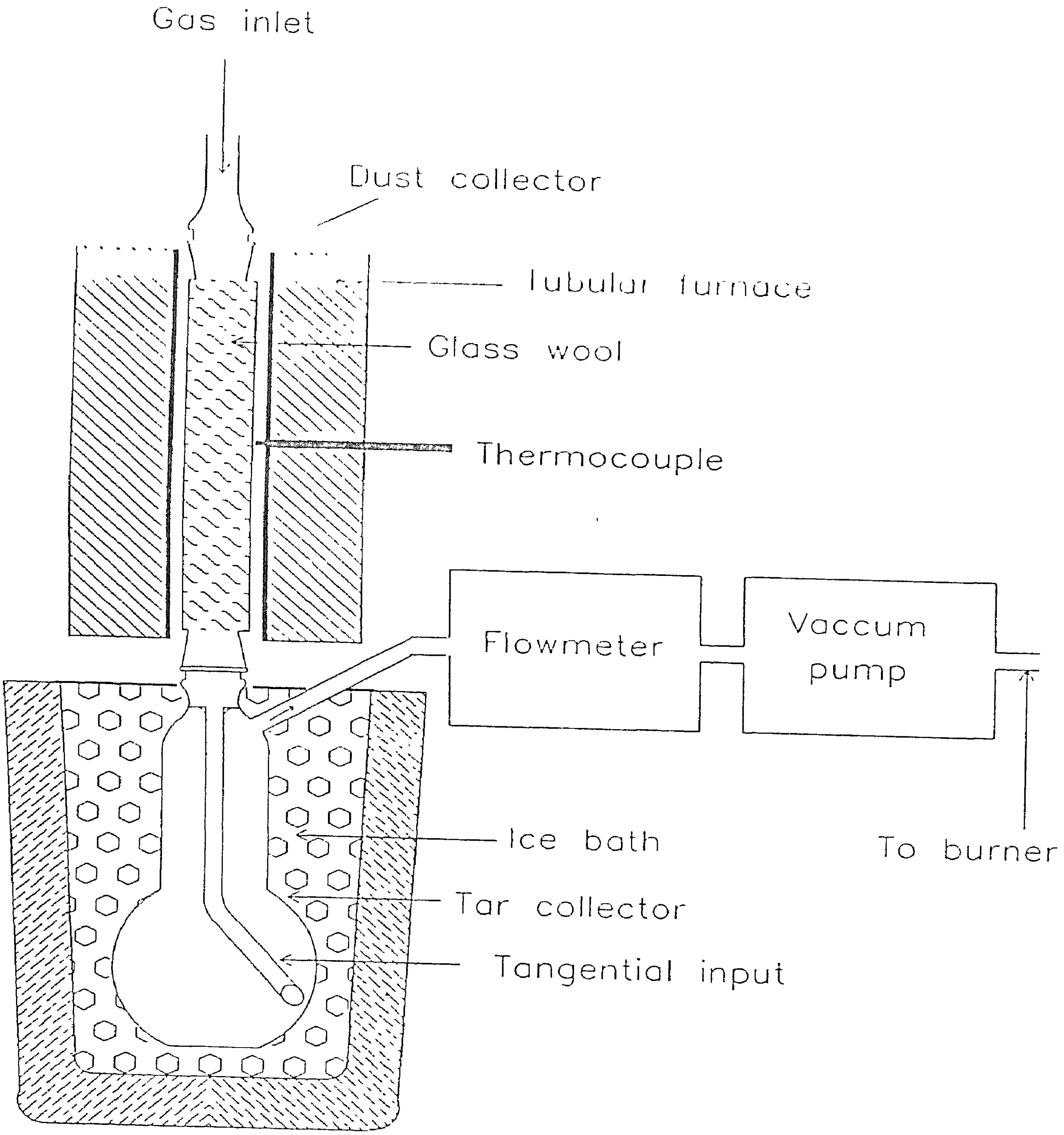


Figure 7.2 . Tar collector with tangential input

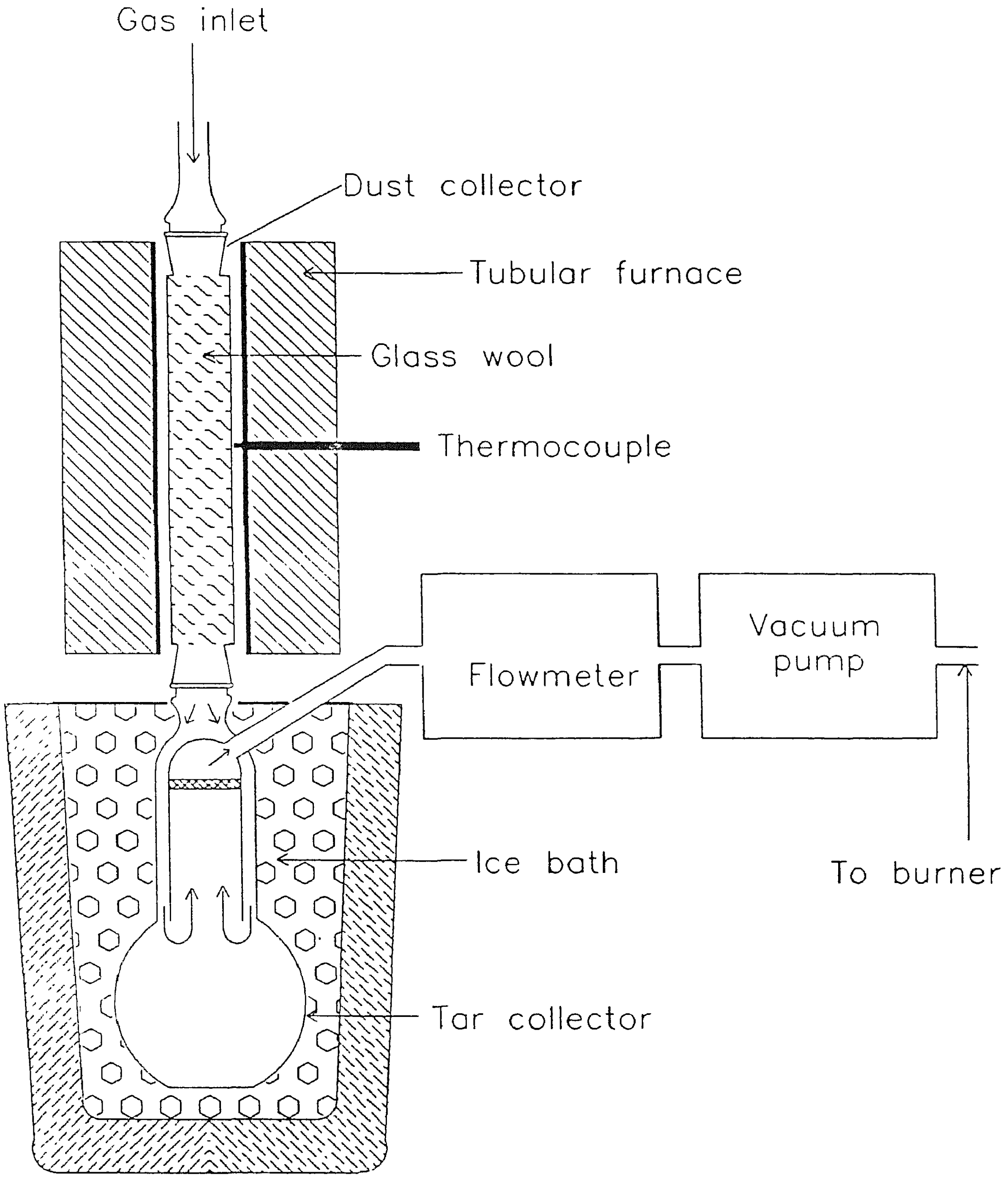


Figure 7.3 : Final design of the gas sampling system

the sampling system shown in fig.7.3 was arrived at in which the gases were allowed to pass through a narrow annulus and exited through a sintered glass plug. The dust collector was mounted directly on the tar collector in a vertical tubular furnace, thus eliminating condensation of tar in the pipe connecting the two. With this design, the amount of tar collected in secondary collector was found to be negligible. The parameters which remained to be standardised were i) the porosity of the bed in the dust collector ii) the dimensions of the dust collector iii) the dimensions of the tar/moisture collector iv) the temperature of the bed in the dust collector, v) the flow rate of gases (or sampling time) and vi) the total amount of gas to be sampled. The total amount of gas to be sampled was kept initially at 1 m^3, and later reduced to 250 l, considering the sensitivity of the balance used to weigh the samples. After several trials, it was found that condensation of tar in the dust collector could be avoided if the bed of glasswool was kept between 250-300°C. The bulk density (degree of packing) of the glass wool fibre in the dust collector will affect the effectiveness of the collecting device and hence experiments were carried out with various bulk densities. The size of the dust collector and the flow rate of gases can be combined into one single parameter, viz., the residence time of the gases inside the collector, which is defined as

$$t = V/Q$$

where, V is the volume of the dust collector in m^3 and Q is the volumetric flow rate of gases in m^3/sec. A similar definition is also valid for the tar/moisture collector. Experiments have also been conducted on the degree of collection achieved with respect to gas residence time, by varying the flow rates of the gases. A control valve placed either at the inlet or exhaust of the vaccuum pump could not effectively moderate the flow rate as severe fluctuations in flow rate were noticed. The problem was solved by bifurcating the exhaust line of the vaccum pump and installing a bypass valve in one of the lines, which allowed a smooth control of the gas flow rate.

Experiments conducted in the beginning showed a wide scatter in the points. The effect of bulk density of the glass wool packing on dust collected is shown in fig. 7.4. As can be expected, the dust collected increases with bulk density and then remains roughly constant. No particular trend could be detected on the effect of residence time on dust collected (fig. 7.5) as the scatter of points is too large. An unexplainable trend was observed regarding the effect of residence time on tar collected, as shown in fig. 7.6. At low residence times, the tar collected should have been lower, or at the most constant, but the data show a decrease in the amount of tar collected with residence time. A possible explanation for fig. 7.6 could be that at the higher gas velocities corresponding to lower residence times, some particulate matter as well as some glass fibers were carried away into the tar collector and were deposited there, registering a higher weight than would be obtained otherwise.

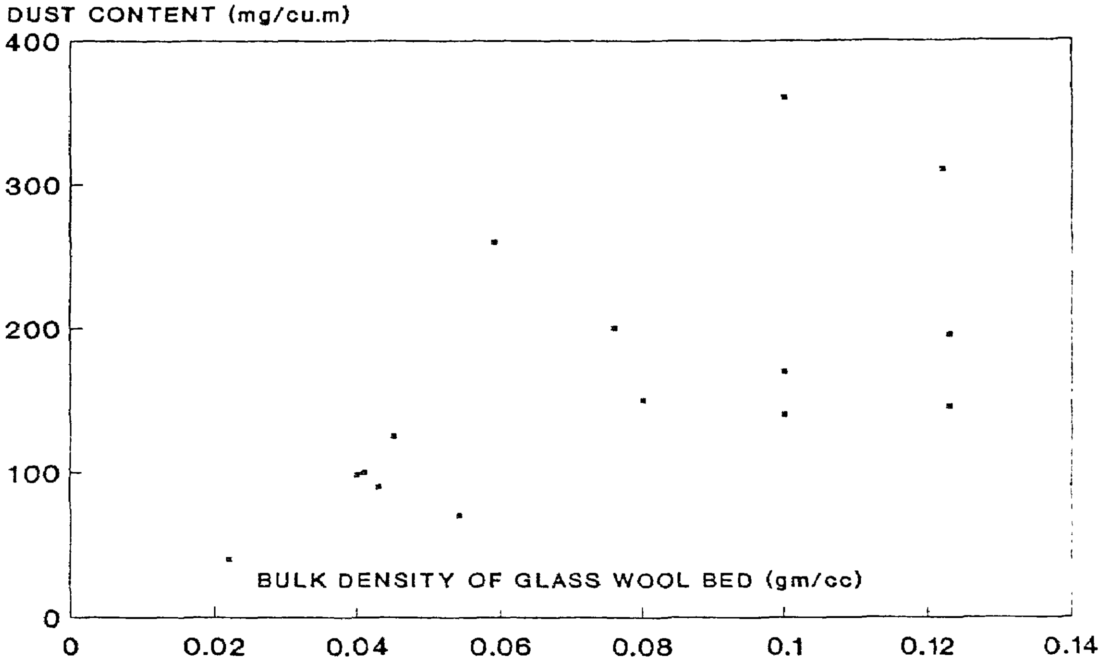


Figure 7.4 : Effect of bulk density of the glass wool packing on dust collected

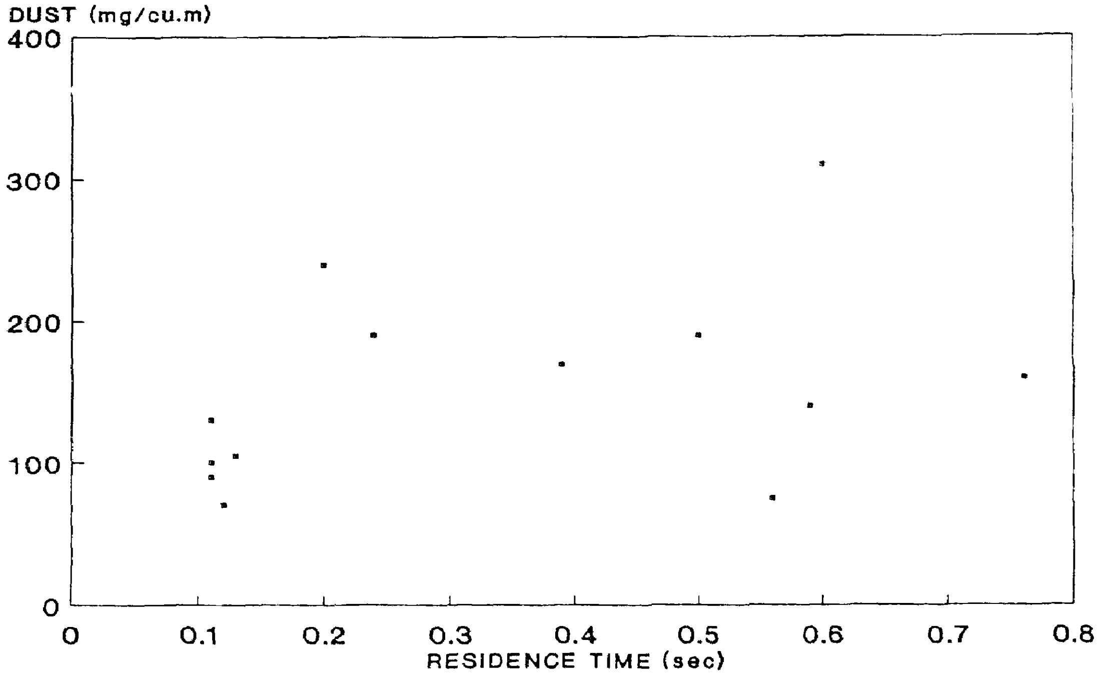


Figure 7.5 : Effect of gas residence time on dust collected

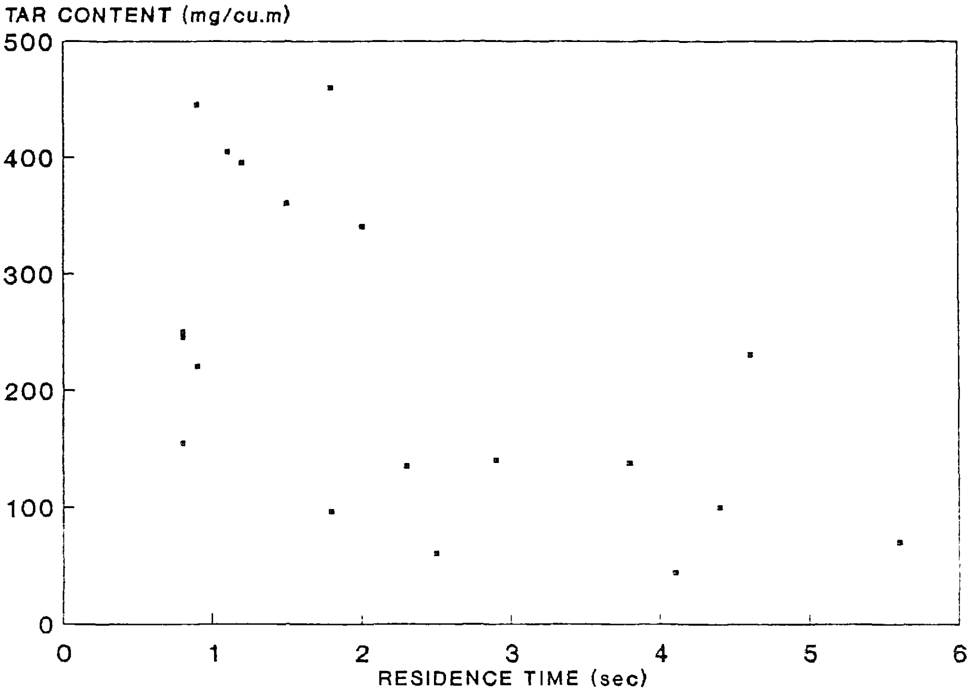


Figure 7.6 : Effect of gas residence time on tar collected

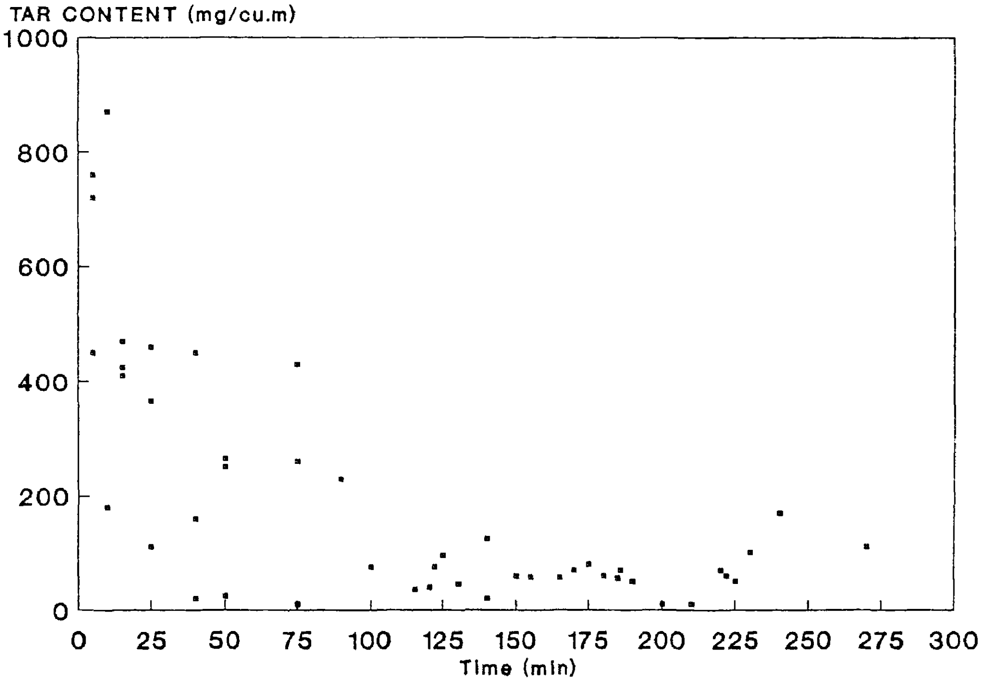


Figure 7.7 : Variation of tar content in the raw gas with time

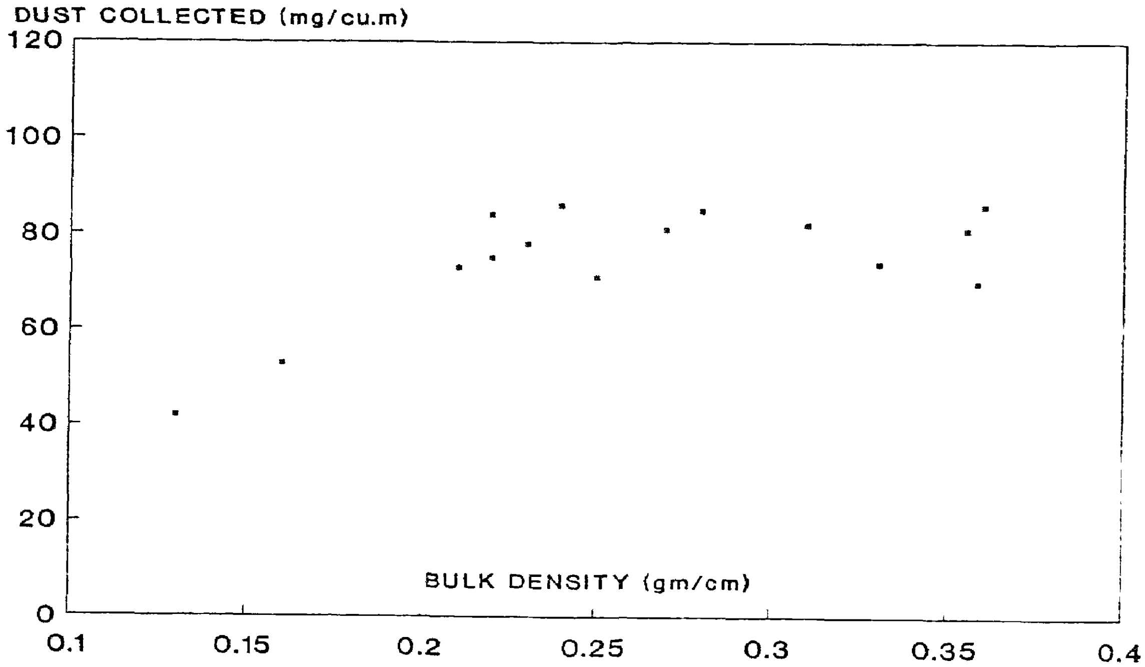


Figure 7.8 : Effect of bulk density on dust collected under steady operating conditions for the gasifier

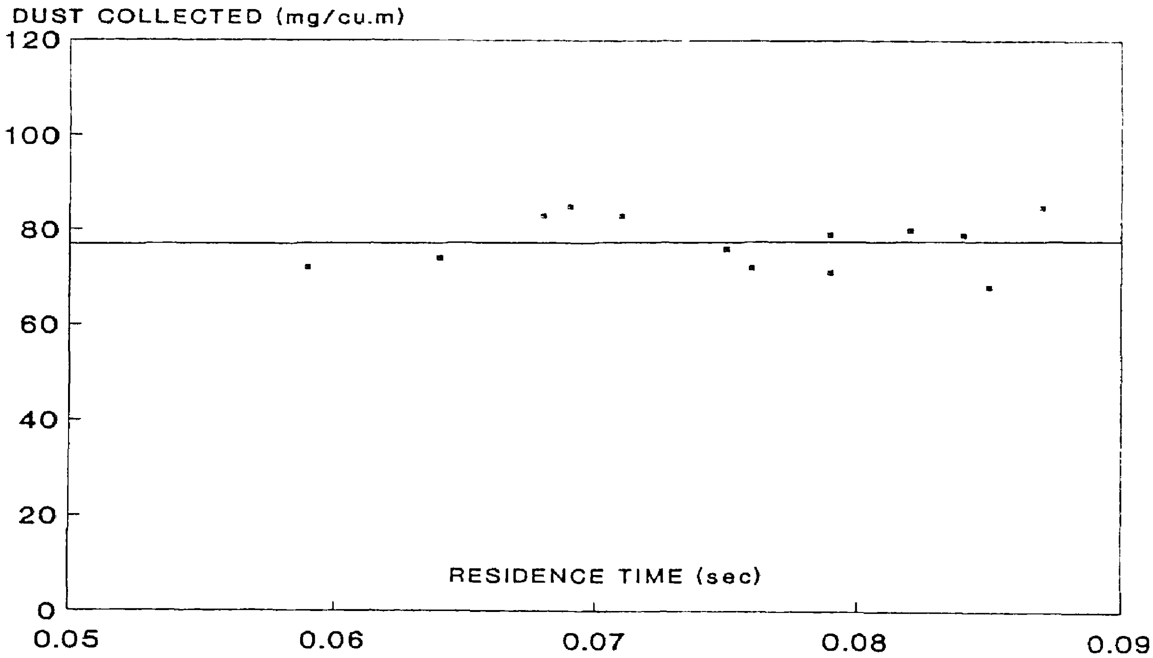


Figure 7.9 : Effect of residence time on dust collected under steady operating conditions for the gasifier

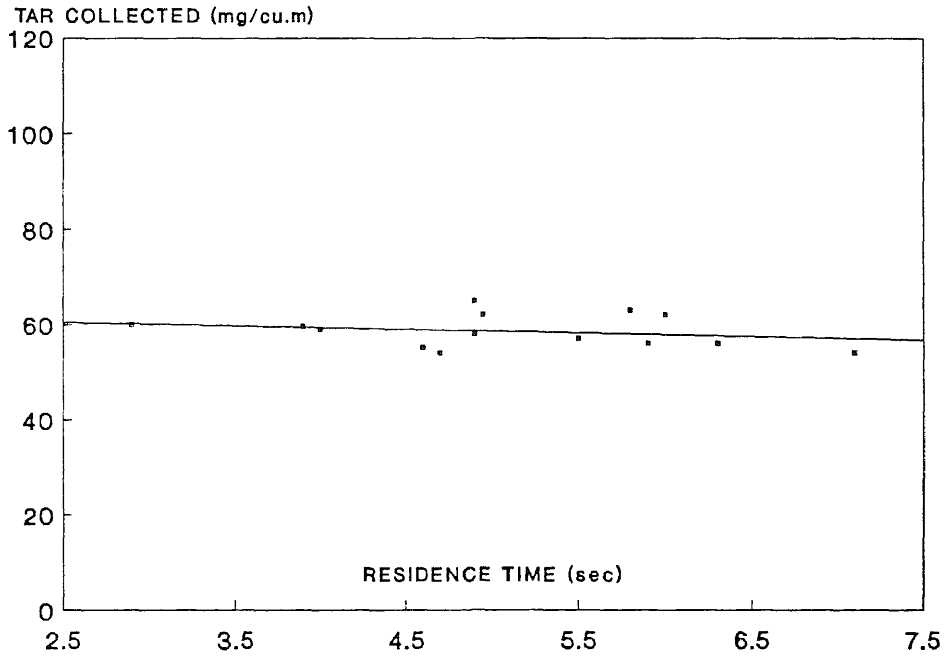


Fig 7.10 : Effect of residence time on tar collected under steady operating conditions for the gasifier

The large scatter in the points could not be explained in the beginning. Later experiments indicated that there is a steep decrease in the tar content of the gases with time, as shown in fig. 7.7, which means that it takes certain time for the gasifier to attain an equilibrium condition in which the tar content would be almost constant. Experiments were then repeated, taking care that all the data was collected after attaining equilibrium. The effect of bulk density on dust collected under steady operating condition for the gasifier is shown in fig. 7.8, which shows a very clear trend with a small scatter. From this figure it could be concluded that the bulk density of glass wool should be above 0.25 gm/c.c. to realise effective removal of dust in a single stage. The effect of residence time on dust collected under steady operating condition for the gasifier is shown in fig. 7.9. For the range of residence times obtained in the experiment, viz. 0.06-0.09 sec, it can be said that there is practically no variation in the dust collected. However, it can be concluded from the figure that a residence time above 0.06 sec. assures complete collection of dust in the dust collector, provided that the bulk density is above 0.25 gm/cc. The effect of residence time on tar collected (after attainment of equilibrium) is shown in fig. 7.10. Again, within the range of residence times experimented, viz. 2.5-7.5 sec, there is no variation in the amount of tar collected. However, it can be said that a minimum of 3.0 sec is needed to effectively condense all tar in the tar collector. The above mentioned guidelines can be used to design a dust and tar sampling train effectively.

The technique of estimating tar and dust contents by the above method seems to be reasonably accurate. The variation, at equilibrium, of the dust content was found to be ± 6.1%, while the variation in tar content was ± 7.9%. It is not known whether this variation is due to the experimental errors or due to the changes inherent in the gasifier operation itself. A further account of the dust and tar sampling is given in the papers provided in the Appendix [38, 39].

7.2 **Determination of Chemical Composition** :

Gas chromatography (GC) is the most widely used method of gas analysis. It depends on the ability of certain adsorbent materials to selectively slow the rate of gas passage through a column packed with adsorbent. Hydrogen is slowed least, CO, N_2 and O_2 are slowed to a greater extent and water and CO_2 are slowed to the greatest degree. The gas sample is mixed with a carrier gas such as Helium or Argon. A detector which is inserted into the gas stream at the end of the column records on a chart recorder both the time of passage and the quantity of each component. The presence of a particular gas component is indicted by a peak. The quantity of that gas is then determined by integrating the area under the peak in the curve and compared with that in a calibration gas of known composition. The most common GC detector performs analyses by measuring the thermal conductivity of the gas, and is most suitable for producer gas measurement.

In the present work, considerable effort was put to use an existing Nucon gas chromatograph for analysis of gas. As hydrogen is a component to be analysed, it cannot be used as a carrier gas. Consequently, helium and later Argon were used as carrier gases. The detection system was by the thermal conductivity detector (TCD). After unsuccessful trials with columns such as Poropak, Molecular Sieve 5A etc. Carbosphere was used upon the recommendation of the manufacturers. The column did seperate all the components of the producer gas, but the values of composition obtained were inconsistent, always showing a too high concentration of hydrogen and a too low concentration of carbon monoxide. The availability of suitable calibration gases was also a problem. Further, the time taken in conditioning the column, calibrating the system etc. was too long and hence it was felt that use of the simpler but less accurate Orsat apparatus would be more desirable. The Orsat apparatus, supplied by a local manufacturer, can detect CO, H_2, CO_2, O_2 and hydrocarbons. The composition of N_2 was determined by difference. All the composition values reported in section 8 were obtained by Orsat apparatus.

8. PERFORMANCE OF THE FIRST PROTOTYPE UNIT

The gasifier system was operated with several fuels and the performance of the system with each fuel is described below.

8.1 Performance with wood chips :

Wood chips have been used mainly for standardising the measuring systems and to study the test performance of the gasifier and associated subsystems. Both smaller chips (4 cm x 4 cm) and larger chips (4cm x 12 cm) have been used in performance studies. The average composition obtained is shown in Table 8.1.

Table 8.1 : Chemical composition of gas obtained from wood chips

Size	No. of runs	Composition (% by volume) CO	H_2	CO_2	O_2	C_nh_m	N_2
4cm x 4 cm	9	14.1	12.3	13.1	1.2	0.2	59.1
4cm x 12cm	7	13.2	12.8	13.1	0.4	0.3	60.2

The standard deviation for concentration of each component was less than ± 1.8. The small amounts of O_2 present in the samples, as discussed in section 4, indicate slight leakages of air while drawing the gas into the sampling tube. The composition of nitrogen obtained by gas chromatography was found to be lower (40-45%), but as described in the earlier section, there were problems in obtaining correct composition of CO and H_2. The tar, dust and moisture contents are shown in Table 8.2.

Table 8.2 : Tar, dust and moisture contents for gas obtained from wood chips

Sample position	No. of experiments	Tar mg/Nm^3	Dust mg/Nm^3	Moisture g/Nm^3
Raw gas	6	89.6-145.2	22.0-138.8	19 - 20
After cooler	7	7.0-37.0	6.0-25.0	1.0 - 7.6

The wide variation in the tar and dust contents can be attributed to the fact that gas contaminants decrease steeply with increasing time as shown in fig. 7.7 of section 7 and no distinction has been made in table 8.2 between gas obtained at different times from start up.

As can be seen from table 8.2, the quality of gas after the cooler itself was good enough for engine application. Hence no measurements were made after the filter, as the gas quality would be even better. Gasifier literature generally gives the picture that high levels of tar content are invariably obtained at low specific gasification rates. For a specific gasification of rate of 0.03 Nm^3/cm^2-hr obtained with the present gasifier, the tar contents are remarkably low. This can be attributed to the large fire box temperature (~ 1500°C) attained by insulating the fire box.

The temperatures of the gas at inlet and outlet of the cooler were 100-120°C and 32-34°C respectively. The pressure drop across the cooler was 4 mm W.G. (max) and the drop across the dust filter was 10 mm W.G (max).

The diesel pump was operated for a total of about 150 hrs, the maximum continuous running time being 5 hours.

Consistent diesel replacement values between 65-70% have been obtained over prolonged periods.

While testing the performance of the gasifier with wood, it was observed that, though there was no problem of ash accumulation or clinkering on the grate, the fuel movement was not smooth, which necessitated shaking or poking occasionally. This was attributed to the erroneous selection of the sidewall slopes of the fuel bin. A mechanism for fuel bed agitation (vibrating type) is shown in fig. 8.1 was tried with partial success, but the device was not effective when the hopper was full. Later, a ribbon-type agitator, shown in fig. 8.2 had been successfully employed for pushing the fuel into the combustion zone as and when the need arose.

8.2 Performance with rice husk briquettes :

Rice husk briquettes supplied by ISGEC were tried in the gasifier on blower mode. The briquettes were made by ISGEC using the binderless technology and were very dense. However, there were no problems in igniting the bed and combustible gas was obtained within 10 minutes of igniting the bed. A charge of 5.5 kg briquettes could be run for 50 minutes, giving an approximate specific gas production value of 1.5 Nm^3/kg. No clinker formation was observed.

Analysis of the char collected in the ash collector showed that the char contained about 27% of carbon. This indicates that the residence time is lower and hence all the carbon in the fuel is not converted. Trials with a high ash

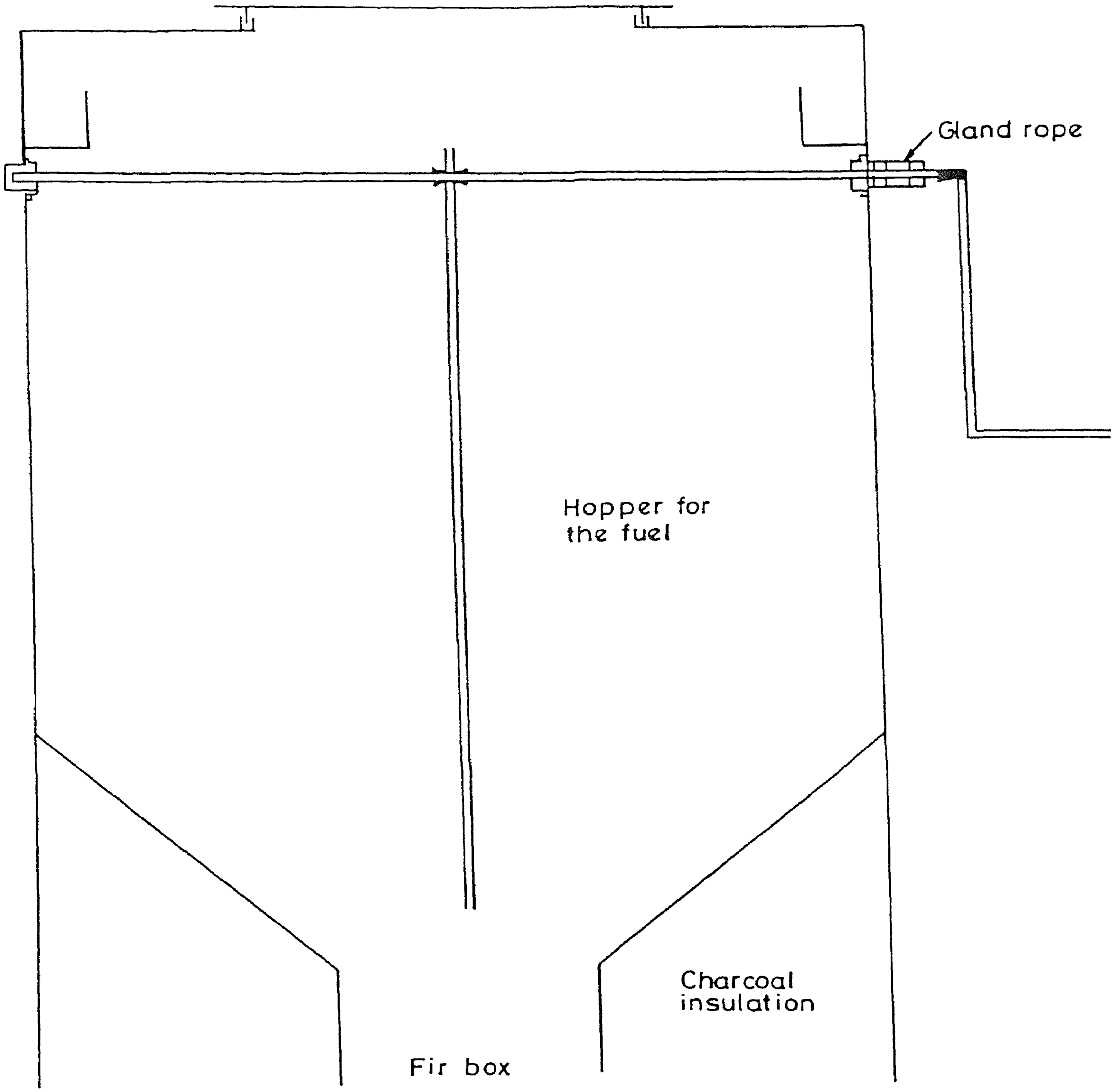


Figure 8.1 : Mechanism for fuel bed agitation (vibrating type)

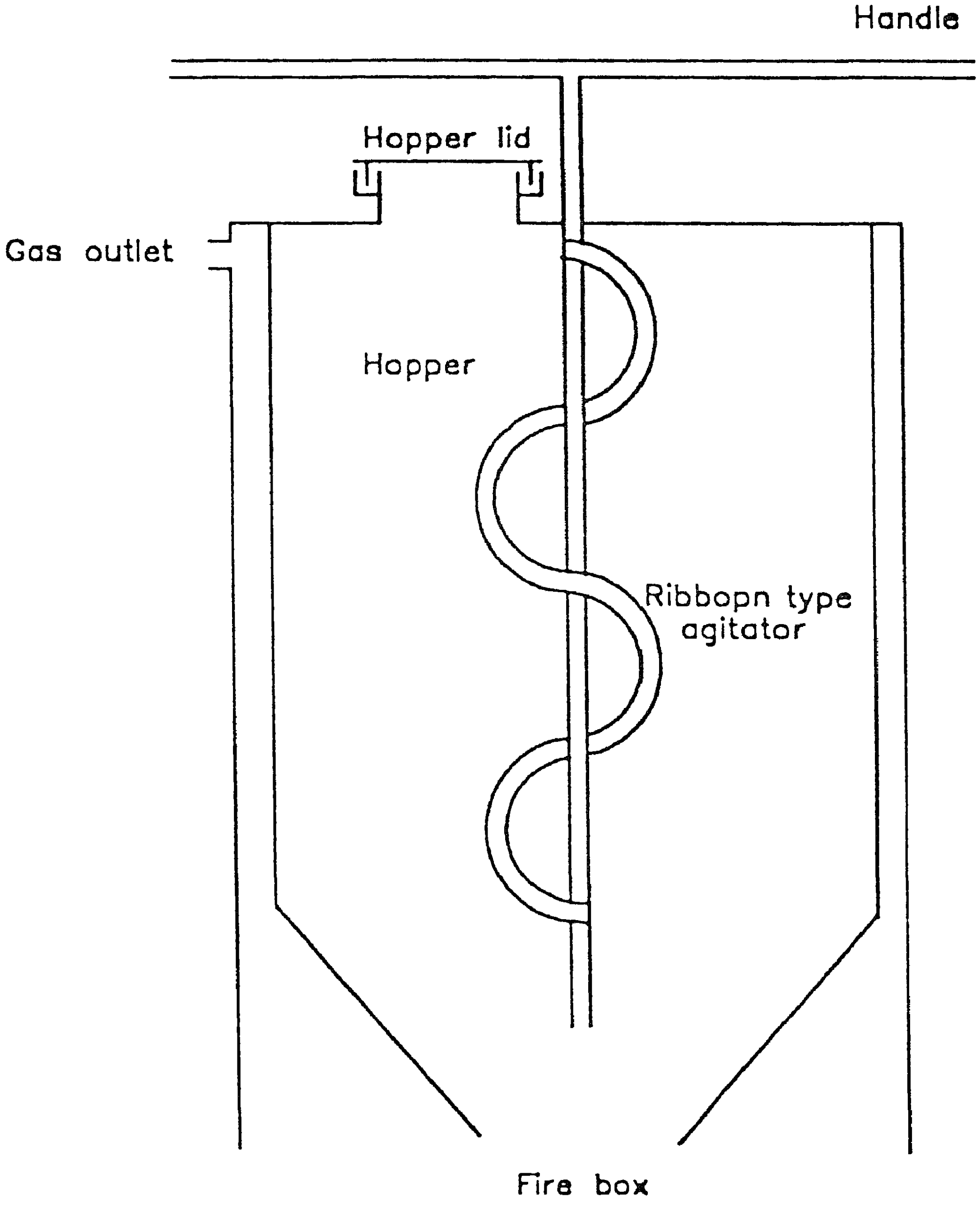


Figure 8.2 : A ribbon—type agitator for pushing the fuel down.

fuel (≃ 20% ash content) such as rice husk briquettes conclusively proved the effectiveness of the ash removal system employed in the prototype. However, due to lack of adequate quantity of the briquettes, parameters such as gas composition, tar content, diesel replacement etc. could not be obtained.

8.3 Performance with saw-dust briquettes :

Saw dust briquettes obtained both by the binderless technology (supplied by M/s Solar Sciences Pvt. Consultants) and by the screw extruding machine described in section 6 were tested in the gasifier. The gas composition obtained with these briquettes is shown in table 8.3.

Table 8.3 : Composition of gas obtained with saw-dust briquettes (%)

Type of briquettes	No. of runs	CO	H_2	C_nH_m	O_2	CO_2	N_2
High density without binder	3	10.3±1.3	13.6±2.2	1.0±0.2	0.5	15.6±2.7	59.1±0.9
Low density with binder	3	8.1±0.2	14.5±0.5	0	0	16.5±0.6	61±1.2

The tar, dust and moisture contents were also measured, as shown in shown in Table 8.4.

Table 8.4 : Tar, dust and moisture contents of gas (after cooler) obtained with saw dust briquettes

Type of briquettes	Tar mg/Nm^3	Particulates mg/Nm^3	Moisture g/Nm^3
High density, without binder	18.5	11.5	1.0
Low density, with binder	--	446.4	1.0

As can be seen from the above table, high density briquettes give a good quality gas. The tar content of the gas from low density briquettes could not be measured due to an accidental breakage at the time, but the dust content was found to be much higher compared to wood or high density briquettes. The diesel replacement values, obtained in short-run experiments are shown in Table 8.5.

Table 8.5: Diesel replacement values with saw dust briquettes

Type of briquettes	**Diesel replacement (%)**	**No. of hours operated**
High density	60-65	20
Low density	67	15

8.4 Performance with coir pith briquettes

Coir pith supplied by Dr. R. Vasudevan, BHEL, Trichy could be successfully briquetted, as mentioned in Section 6. The gasifier was run on blower mode for 1 hr 20 min first and for 6 hr 15 min later. The results obtained in both these runs are shown in Table 8.6.

Table 8.6 : Quality of gas obtained with coir-pith briquettes

Item	**Run No. 1**	**Run No. 2**
CO, %	8.8	8.7
H_2, %	7.3	9.7
C_nH_m, %	0.4	1.8
CO_2, %	16.5	15.1
N_2, %	67.1	64.7
Tar Content mg/Nm^3	86.9	75.0
Dust content mg/Nm^3	633.0	494.0

It can be seen that the gas obtained is quite clean and that dust contents are quite high. Due to lack of adequate quantity of material, detailed studies could not be undertaken.

8.5 Performance with mustard stalk briquettes

The gas composition obtained with mustard stalk briquettes is shown in Table 8.7.

Table 8.7 : Composition of gas obtained with mustard stalk briquettes (%)

Type of briquettes	CO	H_2	C_nH_m	O_2	CO_2	N_2
Low density with binder	7.9	13.4	0.2	0.1	15.9	62.5

It can be observed that the composition is very similar to that obtained from saw dust briquettes (low density). Though the quantity of mustard stalks available was not a problem, further experimentation on this material was planned to be carried out with the second prototype unit.

8.6 Performance with Bajra Stalks :

Briquettes made in the same way as for mustard stalks were tested in the gasifier on blower mode for a few hours. Burning gas was obtained within a few minutes, but no further experimentation was done.

8.7 Performance with groundnut shell briquettes :

Groundnut shells obtained from Gujarat (Bhuj) were successfully briquetted and gasified. Burning gas was obtained but no measurements had been carried out.

The testing of the first prototype with several fuels was an important experience. It showed that several residues in the briquetted form can be gasified in the same gasifier without any major problems. The gas composition and diesel replacement values were adequate. The tar content was also within limits. The dust content, however, was found to be high in the gases obtained from low density briquettes. It should be remembered that a cyclone separator was not provided in the first prototype. It was thus decided to include a cyclone separator in the second prototype. The performance of the cooler cum tar seperator and that of dust filter were also satisfactory. As time was a major constraint, all efforts henceforth were concentrated on the field prototype.

9. DESCRIPTION AND OPERATION OF THE COMPLETE FIELD PROTOTYPE BRIQUETTING/GASIFICATION UNIT.

For the first prototype briquetting-gasification system described in the earlier sections electric motors were used for i) continuous ash removal mechanism, ii) initial start-up blower, iii) pulverisation of biomass and iv) briquetting of biomass. A field prototype would not be acceptable if it requires the use of electricity for continuous operation. Driving several mechanical devices with the same prime mover is a complicated task, especially if generation and use of electricity is not envisaged. Field installation and operation would also warrant a careful examination of i) site selection ii) end use selection iii) type and availability of biomass and iv) operation and maintenance constraints. The mechanisms by which solutions to the above problems have been arrived at are described in the following pages.

9.1 Selection of site, fuel and end use :

Three sites were available for installing the gasifier system - i) the TERI campus under development at the village Gwal Pahari ii) the village Berka-Alimuddin near Sohna and iii) the village Dhanawas near Farukhnagar, all in Haryana. The first option, though convenient, would not ensure that the benefits of the system are available to an actual village community, and hence was not considered. The village Berka-Alimuddin was too far and was not desirable from logistics point of view. Hence the village Dhanawas, where TERI was actively involved in various programmes such as afforestation, dissemination of improved chulhas, construction of biogas plants etc., was finally chosen.

To assess the type and quantity of agro residues available in the village, a survey was conducted initially. The survey brought out the following points.

i) There did not exist a standard measure for quantity of crop residue. Data was obtained in terms of tractor loads, camel carts etc., conversion factors for which were not available. Though some farmers gave a rough idea of conversion factors, there was no agreement between them.

ii) The quantity quoted by them did not include that part of the residue which was left in the fields.

iii) All the residues were not transported from fields in bulk. For example, mustard stalk was stocked in the fields and brought home in parts. This complicated the estimation procedure.

However, based on the obtainable data, the availability of various residues in Dhanawas was computed as shown in Table 9.1.

Table 9.1 : Availability of Agroresidues in Dhanawas

Crop	Total annual grain yield, ('000kg)	Total annual residue yield, ('000kg)	Present use or residue
Wheat	343	302	Fodder
Barley	78	105	Fodder
Mustard	41	78	Fuel
Gram	16	18	Fodder & fuel
Jowar	19	41	Fodder
Bajra	36	45	Fodder
Guar	20	51	Fodder & fuel
Groundnut	3	2	--

The purpose of the survey was to estimate the excess waste available. But this could not be achieved because the part of the residue which was used as fodder, fuel or fertilizer could not be obtained with any accuracy. Observations indicated that almost all the straw was being used as fodder. The production of groundnut was small and as no milling was done in the village, shell was not available. Stalk, especially that of mustard, was an essential fuel for cooking purposes. However, some households reported an excess of mustard stalk. It was thus concluded that if a gasifier had to be installed in the village, the most promising candidate fuel would be mustard stalk, followed by Guar and Bajra. Also, briquettes could successfully be made from these wastes, as described in section 6.

It would be interesting to note that the fuel problem was solved by offering a small price. In fact, almost the entire amount of stalks required for the operation of the system for one year could be obtained from a single household. Not surprisingly, the household was one of the few using a biogas plant in the village since 1986 on a regular basis.

It was increasingly becoming clear that the system cannot possibly be used as a privately owned and operated system for irrigation pumping. Also, involving a single individual or household, who would ultimately get the benefits of the system, was not socially desirable. There was no system of community wells for drinking water applications as most of the households had their own source of water or used tap water. Taking all these considerations into account, the most logical thing to do was to generate electricity and supply it for street lighting. Providing electricity for the village temple was also thought to be an acceptable proposition. Besides, the temple authorities were willing to provide the land for installing the system. The system in principle could be used for any motive power application, including water pumping, but from the prevailing situation in the village, it was decided to use it for electricity generation. The village was already electrified, but a few streets did not have lights. The capacity of the system would be too small to couple it to the grid. Hence the gasifier based power plant was decided to be used as a stand alone unit delivering electricity on demand, providing substantial end use/user flexibility.

9.2 Design of the overall layout of the field prototype

In order to tap motive power for driving several devices from the same prime mover (a diesel engine in the present case), the block diagram for the complete briquetting -biomass gasification system is shown in fig 9.1 has been arrived at after several trials both on paper and in practice. The power needed to run the pulveriser and briquetting machine was about 5 hp, as noted in section 6. As some power should be required to run the grate-shaking device in regular operation and as there would be a loss of power due to derating in dual-fuel mode and due to mechanical transmission, the power delivered by the prime mover should be higher than 5 hp. Assuming a derating of 20% and an efficiency of 80% for the transmission system, the power of the diesel engine can be calculated as 7.8 hp. To be on the safer side, a 10 hp engine coupled to a 7 kVA alternator has been finally selected. There was no place to mount several pulleys on the shaft of the engine and hence the engine and alternator were separated and two pulleys were mounted on the diesel engine shaft. One was coupled to the grate-shaking device and the other to a common shaft. Three pulleys fixed on this common shaft are coupled to individual devices, viz., the alternator, the briquetting machine, the pulveriser and a chopping machine. The chopping machine was originally not envisaged, but had to be included later. The

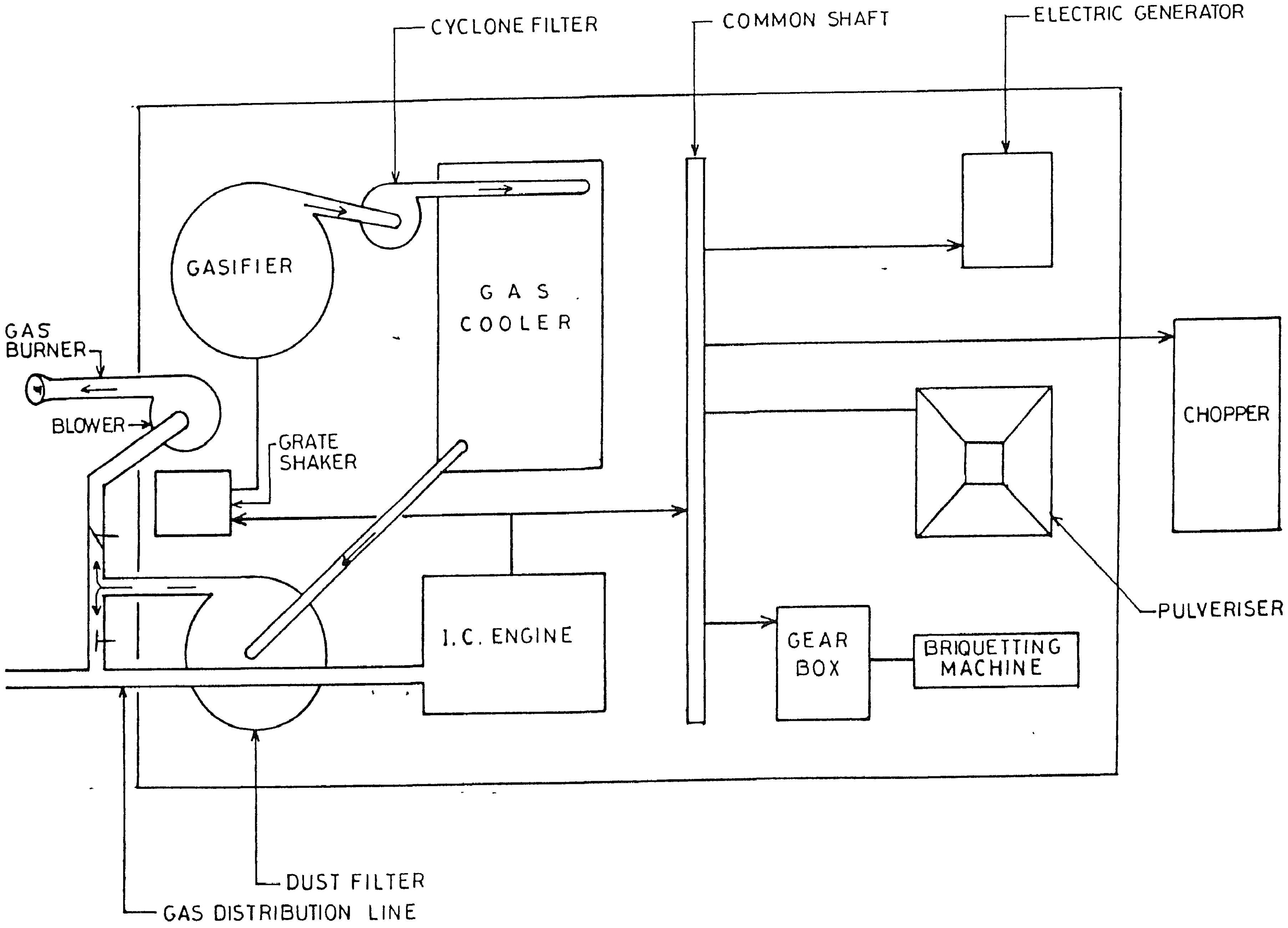


Figure 9.1 : Block diagram for the complete briquetting-gasification biomass gasifier system.

same pulley coupled to the pulveriser can be coupled also to the chopper by using a longer belt. The diameters of the various pulleys were selected in such a way that the rpm requirements of the different devices were met. Two V. belts were used for coupling the pulleys on the common shaft and on the engine as use of a flat belt resulted in a significant loss of power. The coupling from the common shaft to the other devices, however, was by flat belts as it enabled the operator to connect and disengage a given machine easily enough. The diameter of the common shaft was adequate from static load considerations. An ordinary M.S. shaft used at first developed bending and severe wobbling under dynamic loads. A vibration analysis showed that either the diameter should be increased or the span between the bearings be reduced. The problem of bending was ultimately solved by using hardened steel shaft and by providing three instead of two ball bearings. Alignment of the various shafts was a major problem, which took considerable time and effort.

Several attempts were made to operate a blower (needed for the initial start-up) in a mechanical way by coupling it to the shaft of the grate-shaking device. A hand blower was used for this purpose as the usual motor-driven centrifugal blowers were found unsuitable. The shaft of the hand blower was, however, quite small in diameter besides having inadequate bearings, resulting in frequent jamming of the propeller blades in the casing. The attempts were finally given up and a small motor-driven blower was installed for initial start up. The motor was driven by the alternator. All the components of the field prototype - the gasifier, cooler cum tar seperator, dust filter, diesel engine, grate shaking unit, common shaft, briquetting machine, pulveriser and the alternator were mounted on a rigid steel structure resting on load bearing wheels. The field prototype was thus a mobile unit and can be carted to any place by means of a truck. The design details of the components listed above are more or less the same as described in Sections 5 and 6, but a few modifications had been effected, as described below.

9.3 Design and fabrication details of the gasifier and associated subsystems :

It had been shown in the previous sections that operation of the gasifier at low specific gasification rates was perfectly feasible, provided the combustion reduction zones are insulated properly. Heat loss calculations showed that there is a relation between the diameter of the reactor and the insulation thickness and k-value. In order to rationalize the design and to optimise the reactor dimensions, a mathematical modeling exercise was initiated. This exercise provided some insight into the behavior of the pyrolysis zone [40] but could not be extended to the more complicated combustion-reduction zone due to lack of time. A gross heat transfer analysis of the latter however indicated that the diameter was on the higher side, or the specific gasification rate was on the lower side for the first prototype. Hence the diameter of the fire box in the second prototype was reduced to 15cm. The maximum gas demand for the 10 hp diesel engine was obtained as 30 Nm^3/hr and hence the maximum SGR would be about 0.17 Nm^3/cm^2 hr, which is still much less than the recommended value for throated designs. A two-layer insulation scheme, the inner layer being Supercrete (made by ACC) and the outer layer being glasswool, was selected for the fire box. The thickness of each layer was decided from calculated temperature profiles and acceptable temperature ranges for each material. A diagrammatric sketch of the gasifier is shown in fig 9.2. The gas generated passes through the grate and up through the annular space shown, transferring some of the sensible heat to the fuel bed, and finally exits in a tangential manner at the top of the gasifier. Figures 9.3 (a) and (b) give views of the gasifier as seen from below. The adjustable grate with the vibrating arm required for coupling to the grate shaking device is shown in fig. 9.4. The ribbon-type fuel bed agitator with the central air nozzle is shown in fig. 9.5. The air inlet is provided by two horizontal tuyeres and a central tuyer. The gasifier before mounting on the trolley is shown in fig. 9.6. The entire gasifier was insulated from outside using glass wool. The complete gasifier after insulation is shown in fig. 9.7.

The ash removal system, shown in fig. 9.8 is essentially the same as the one employed for the first prototype.

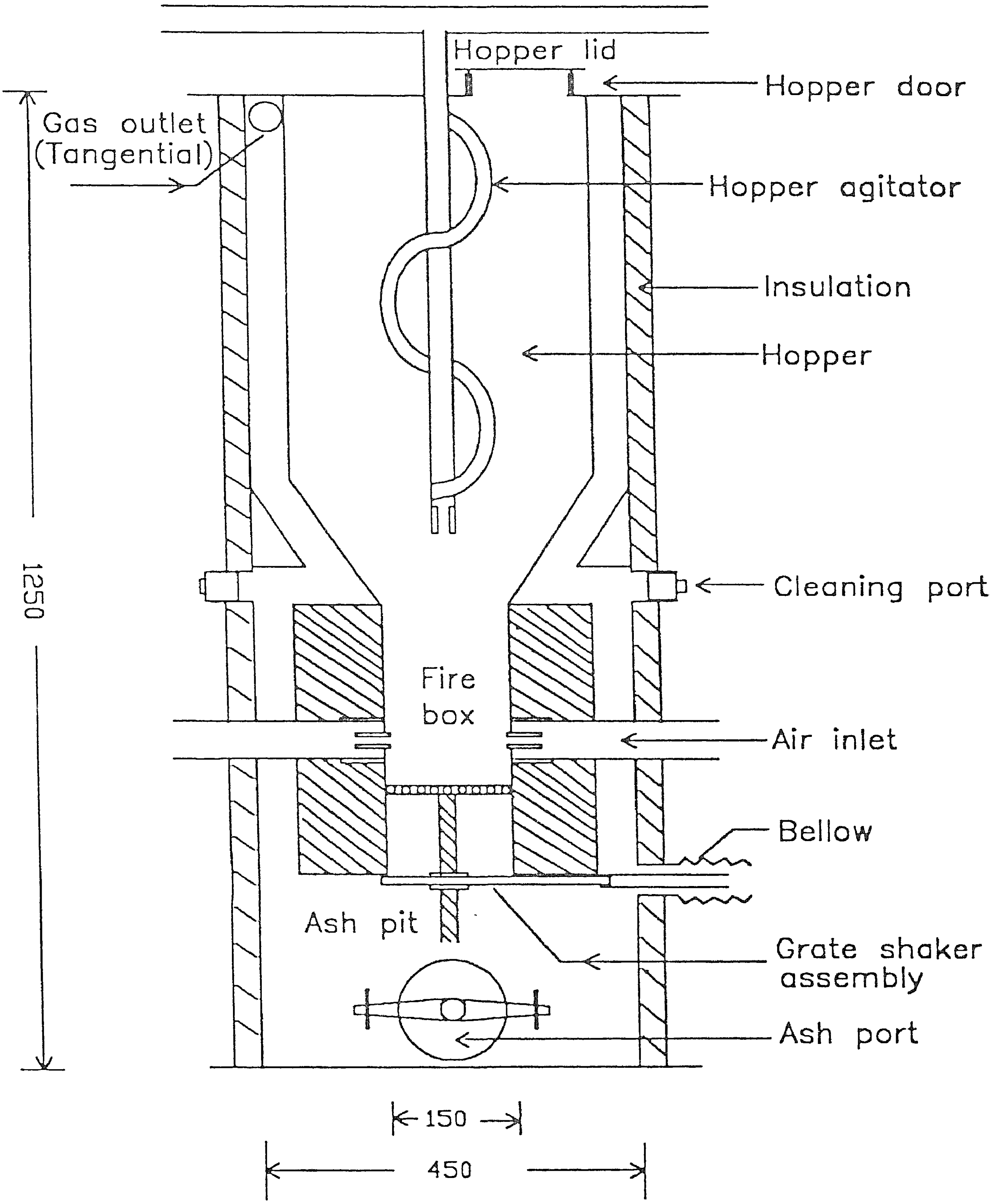
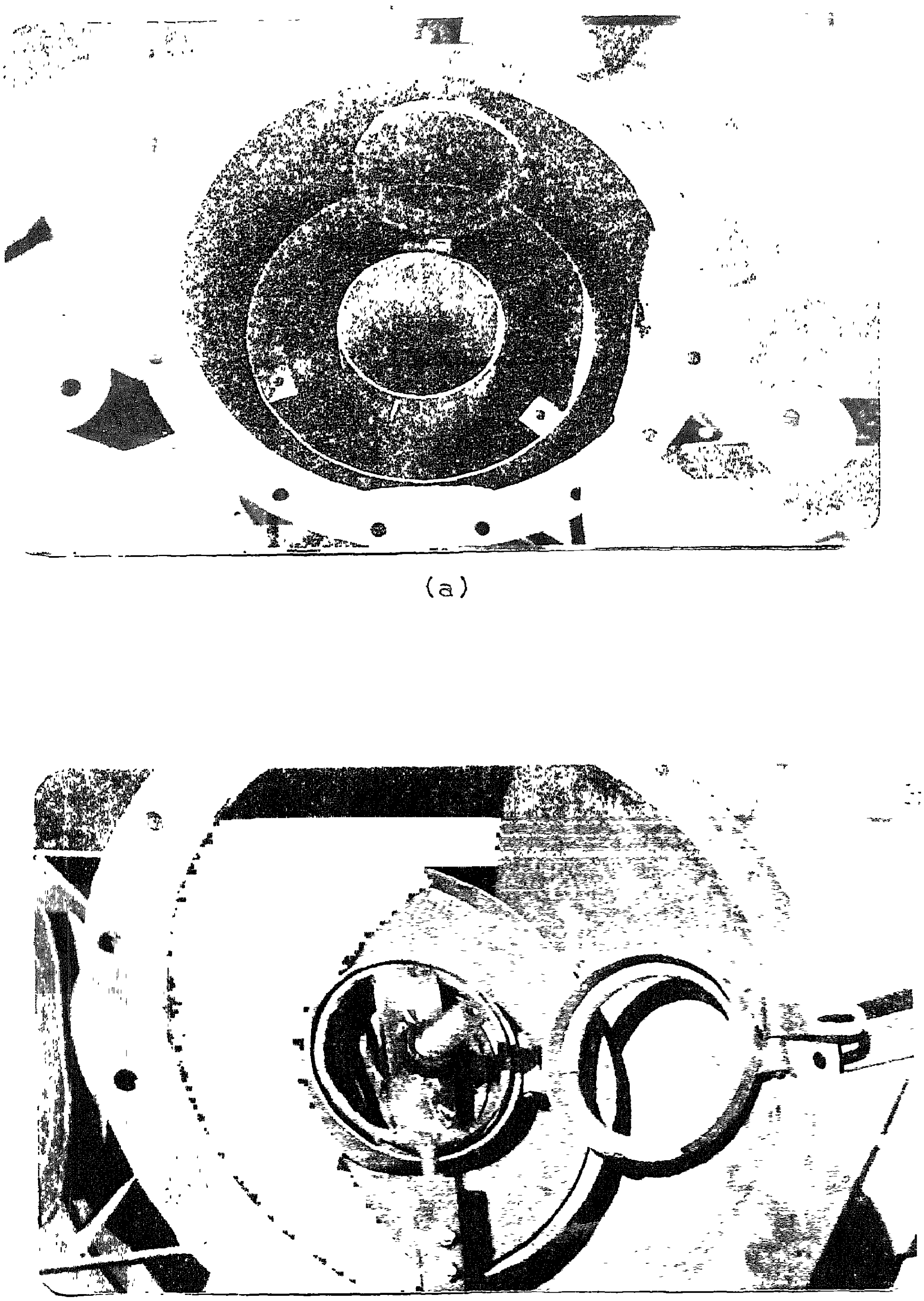


Figure 9.2 : Sketch of the gasifier



(a)

(b)

Figure 9.3 (a) & (b) : A view of the gasifier as seen from below.

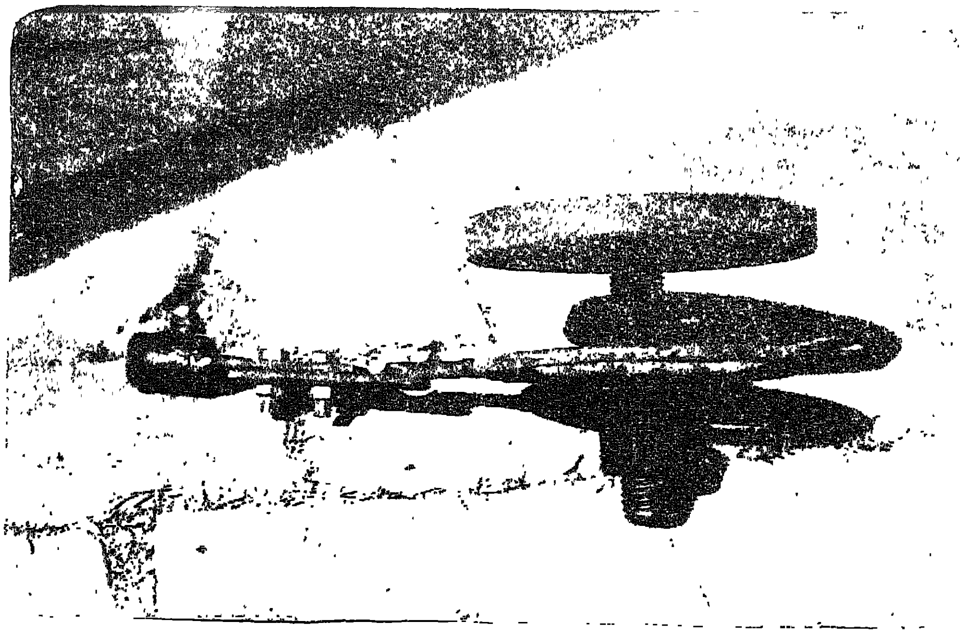


Figure 9.4 : Adjustable grate with vibrating arm required for coupling to the grate shaking device.

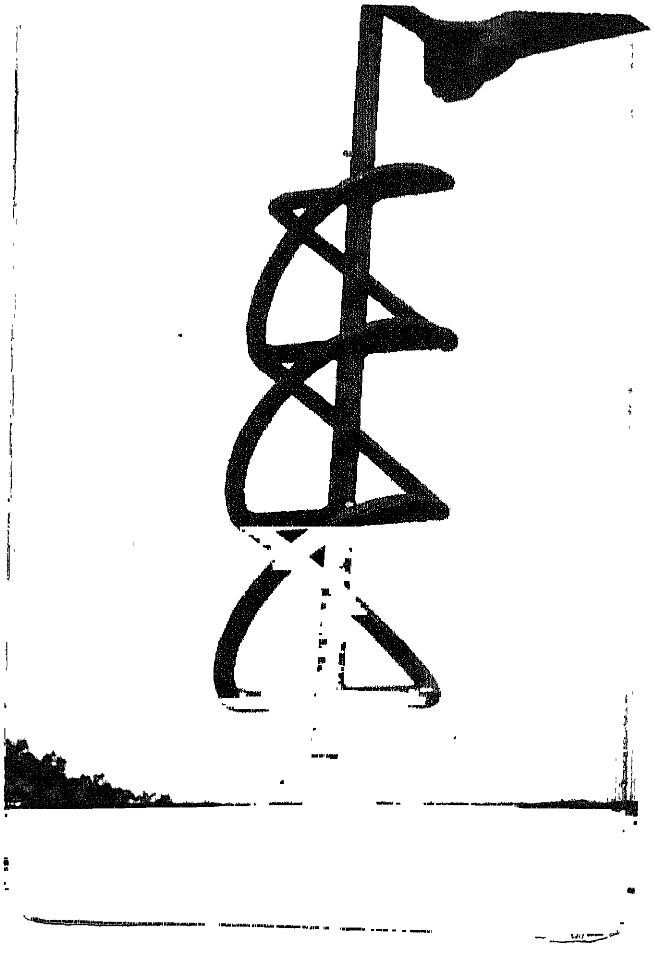


Figure 9.5 : Ribbon type fuel bed agitator with centre air nozzle.

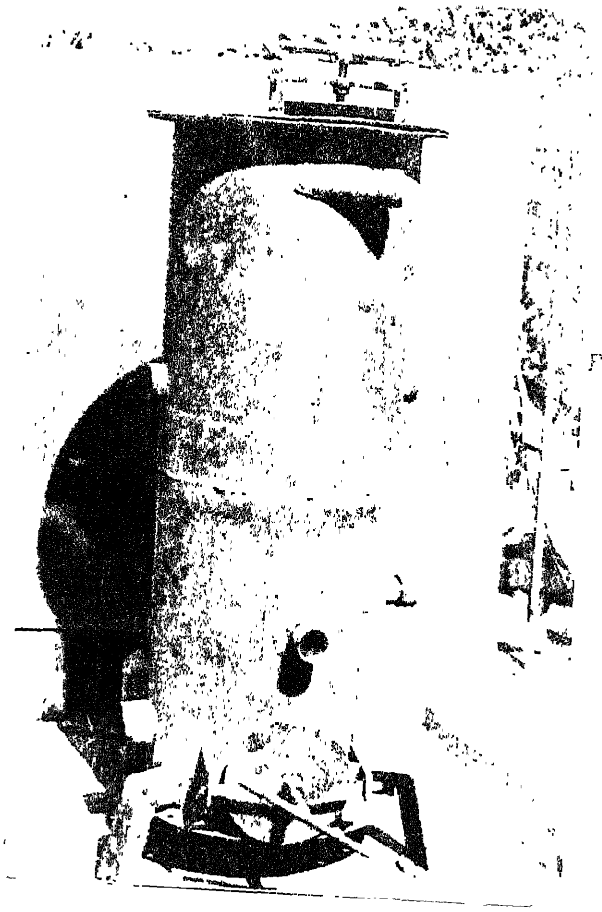
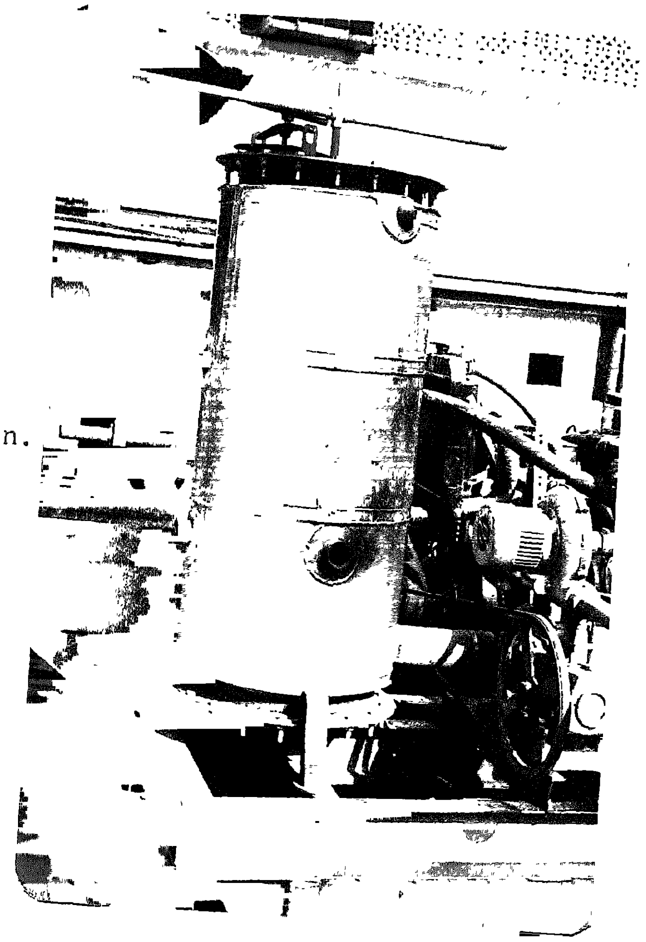


Figure 9.6 : Gasifier before mounting on the trolly.



igure 9.7 : Gasifier after insulation.

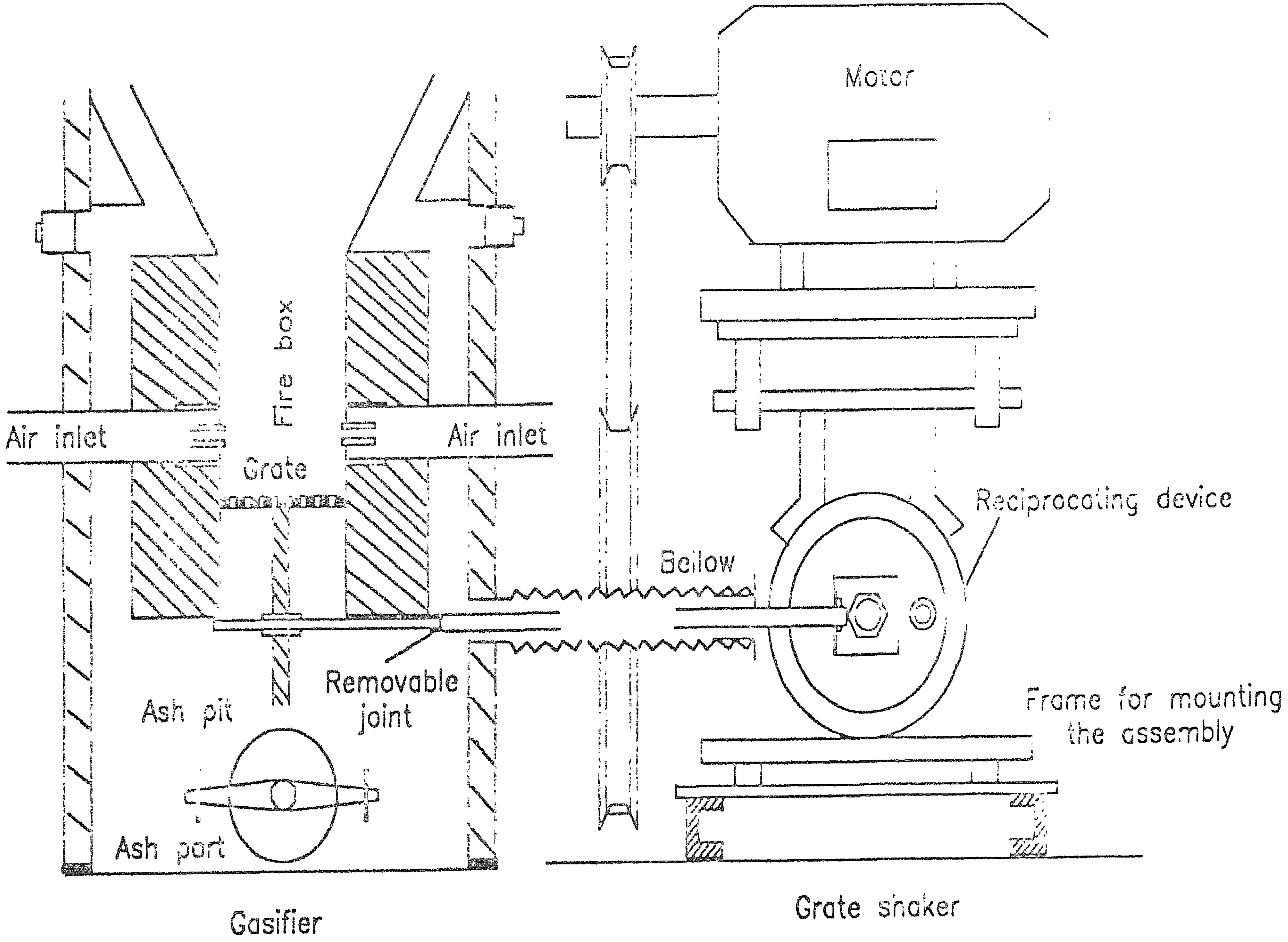
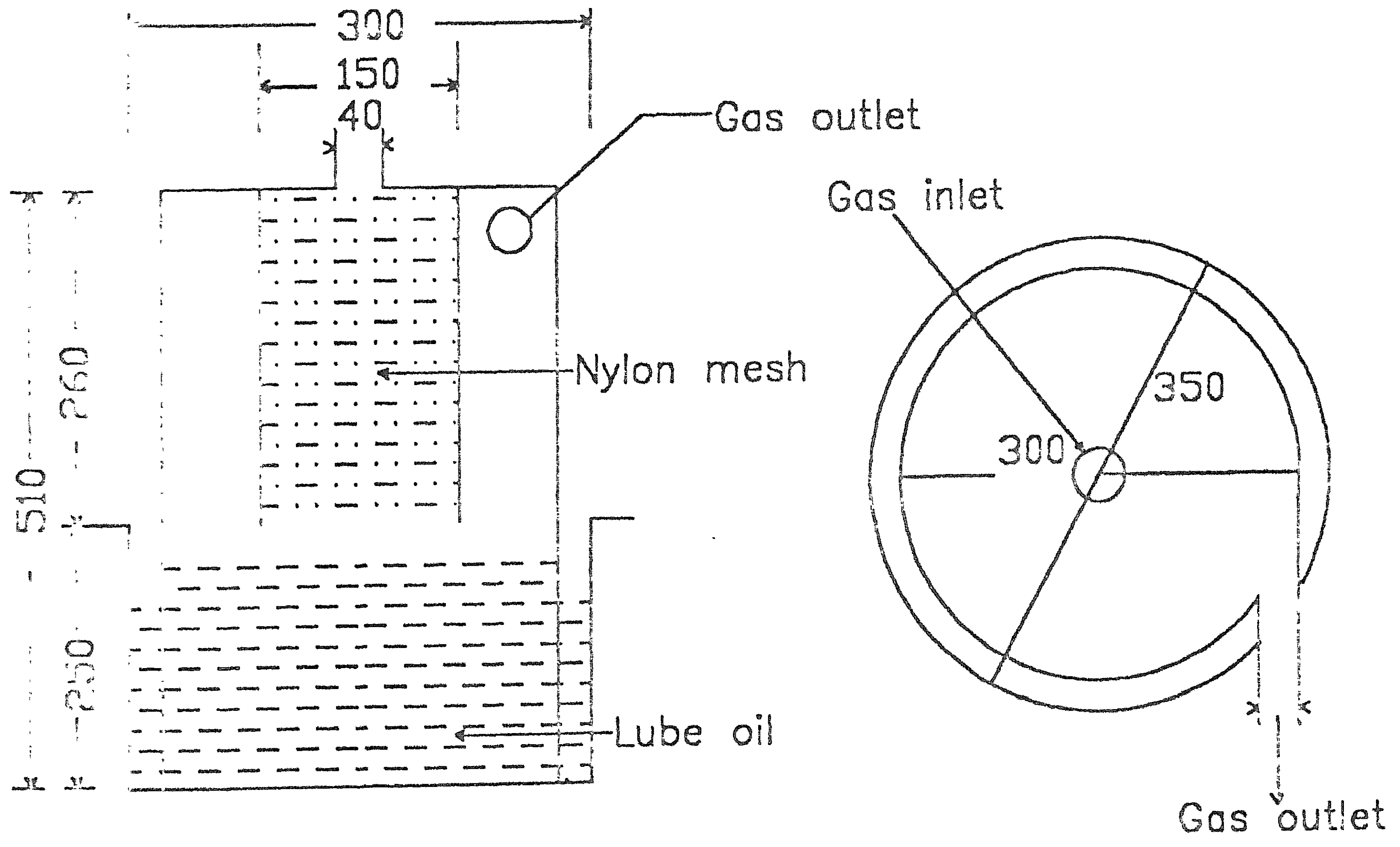


Figure 9.8 : Ash removal system



Sectional view

Top view

Figure 9.11 : Simplified dust filter (New)

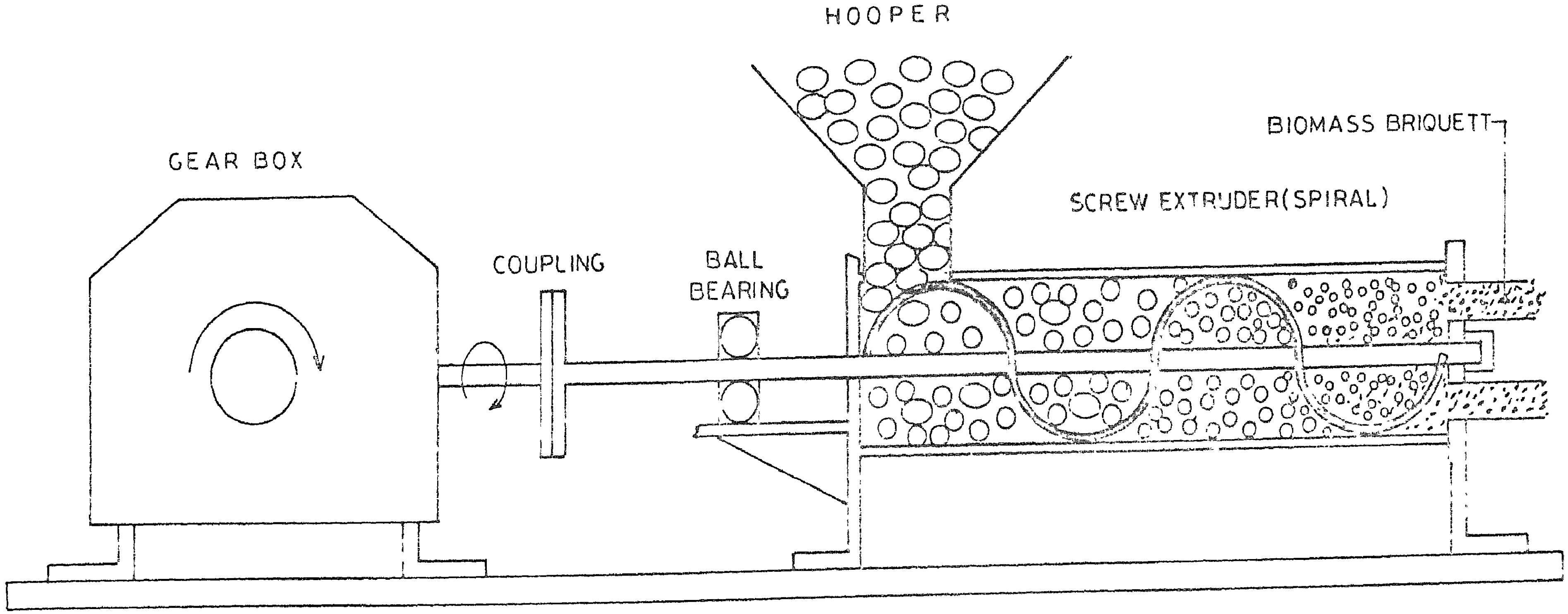


Figure 9.12 : Briquetting machine (New).

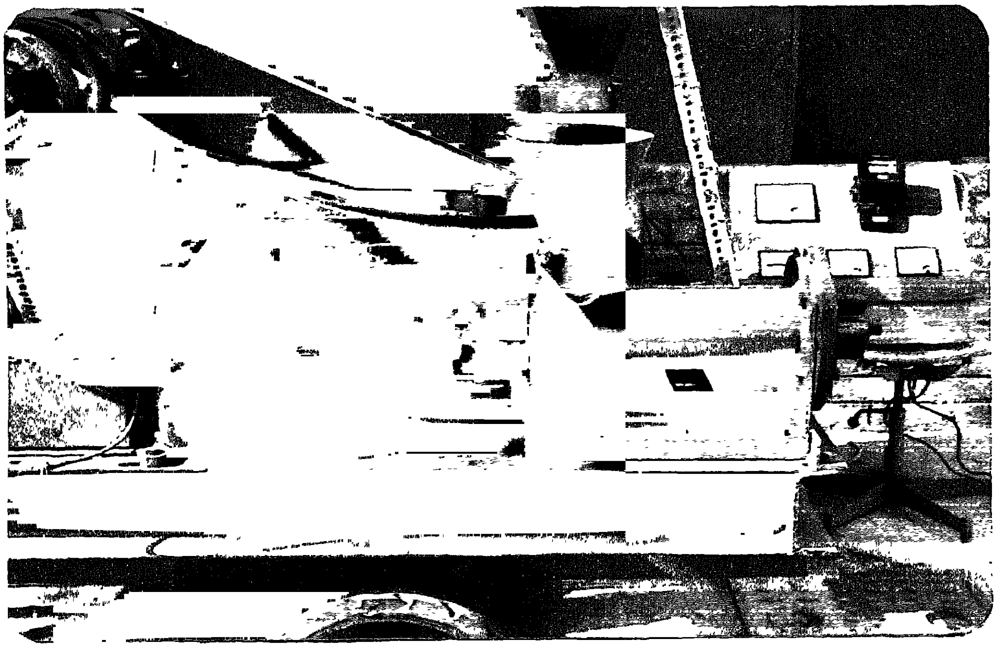


Figure 9.13 : Close view of the briquetting machine.

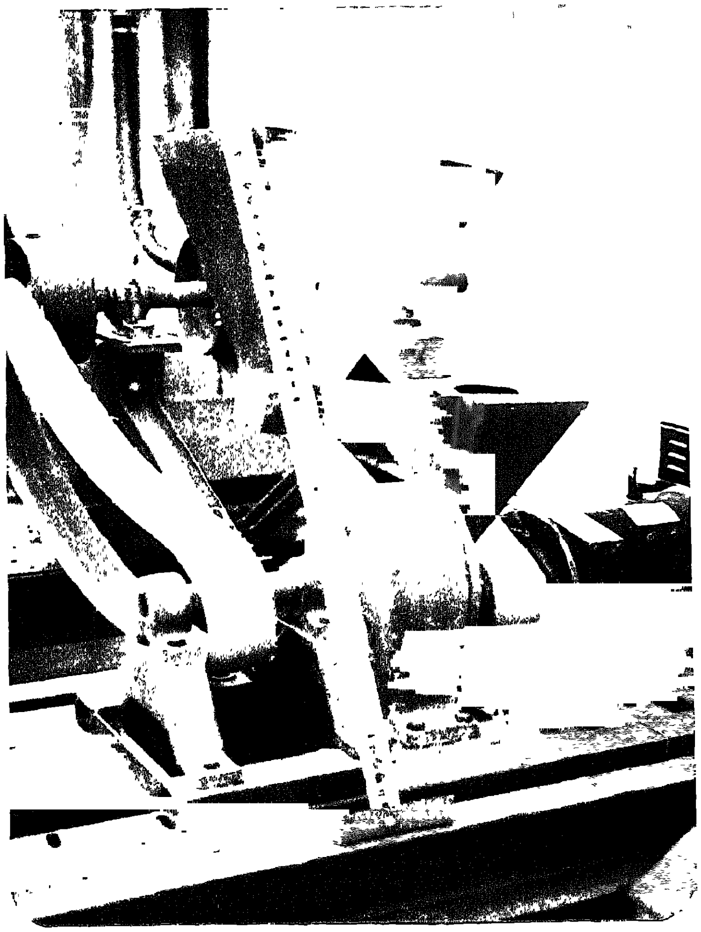


Figure 9.14 : Pulverising machine mounted on the trolly.

Figure 9.15 : Close up of alternator on the field prototype.

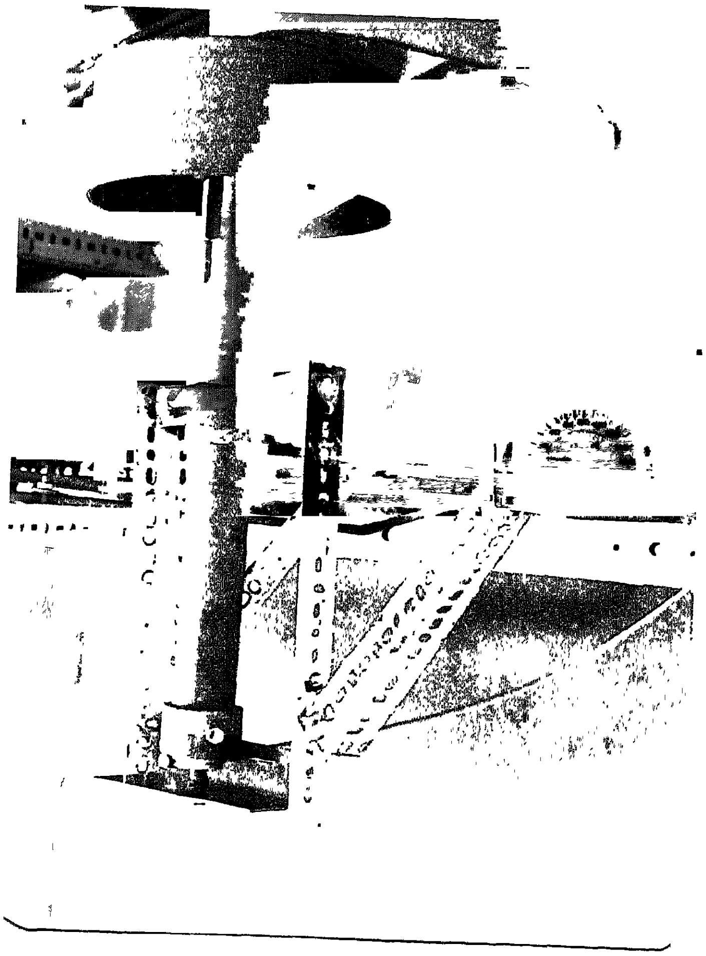


Figure 9.16 : Speedo-meter on the trolly.

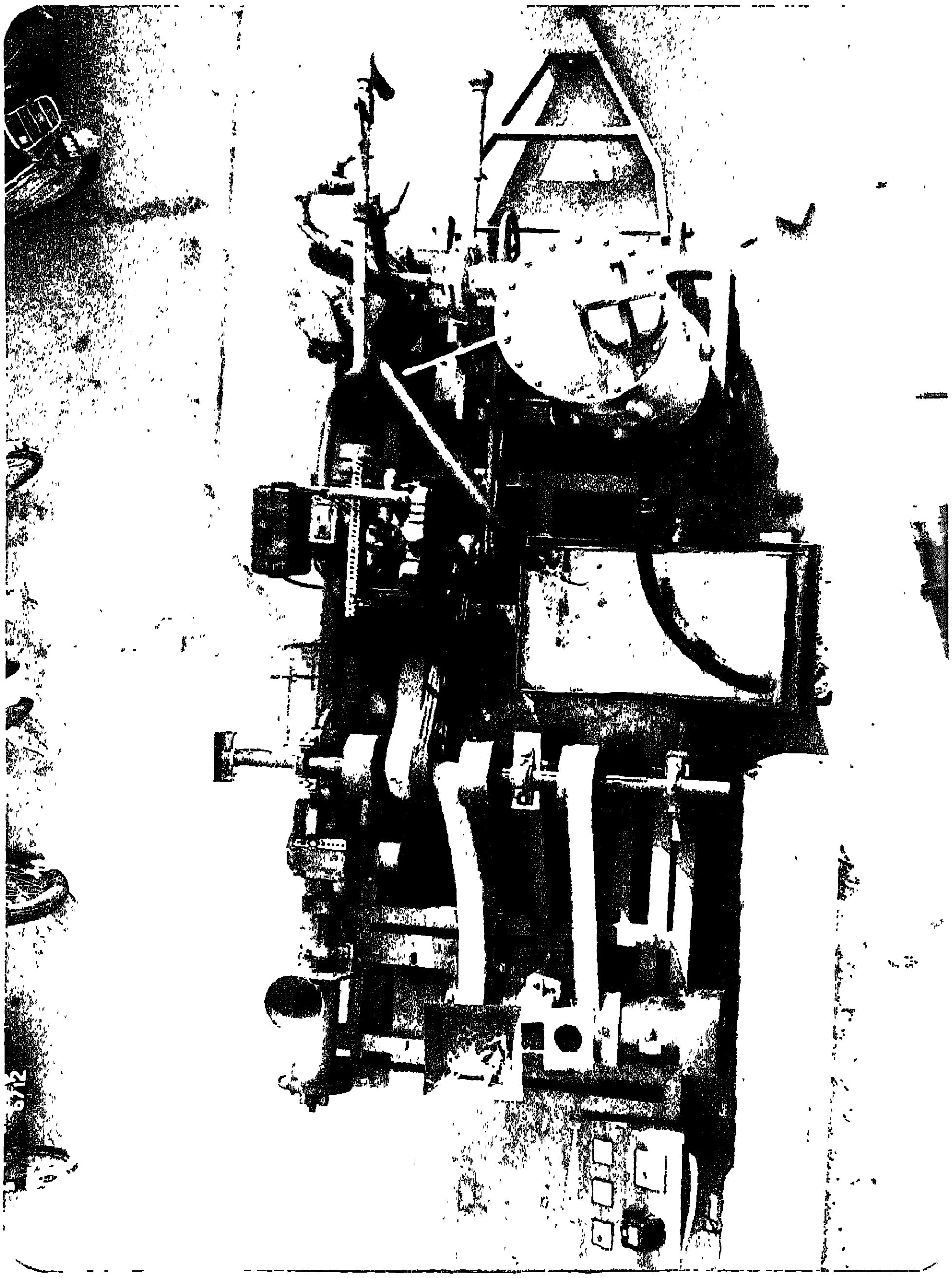


Figure 9.17 : Top view of the trolly.

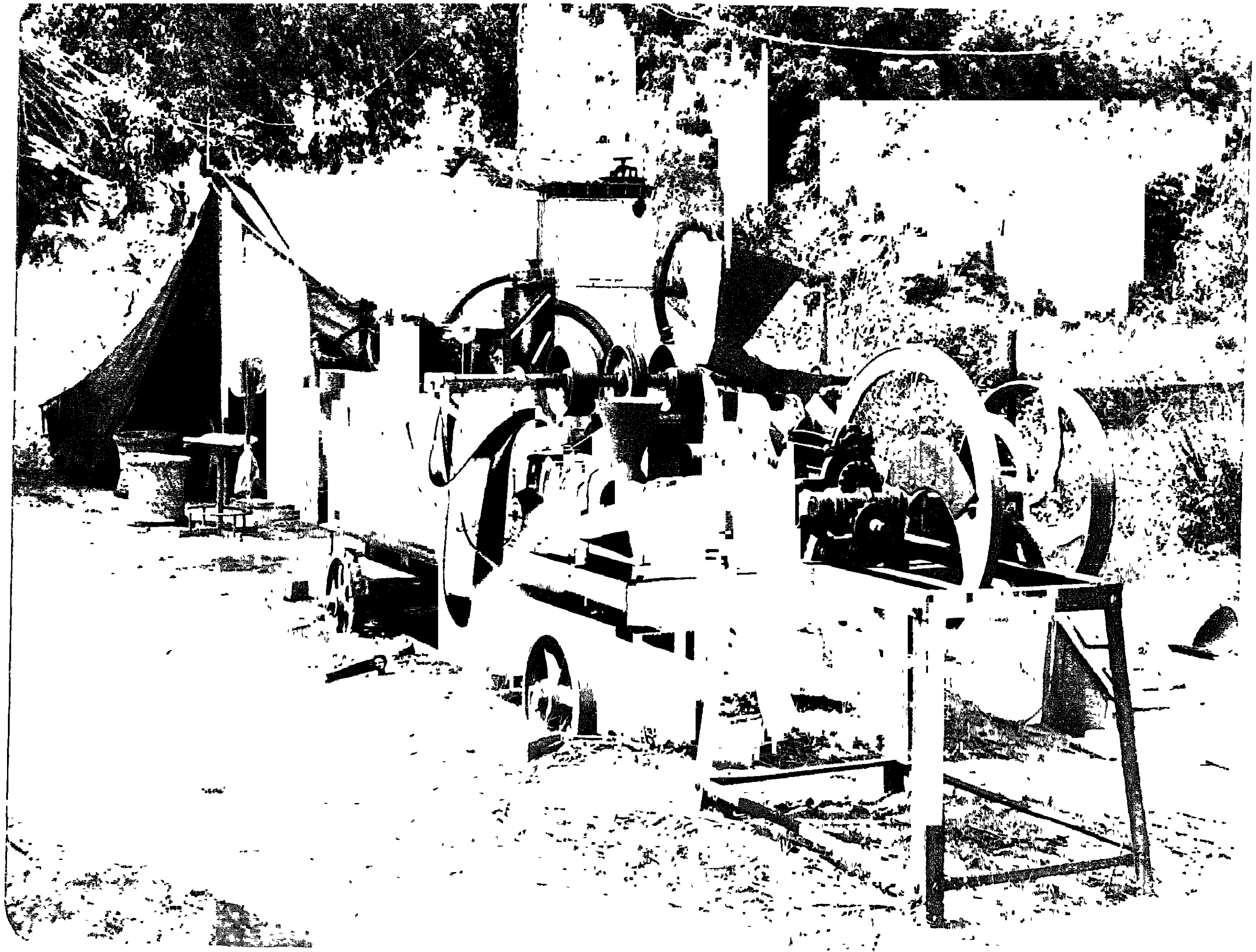


Figure 9.18 : A view of the unit installed at the village site.

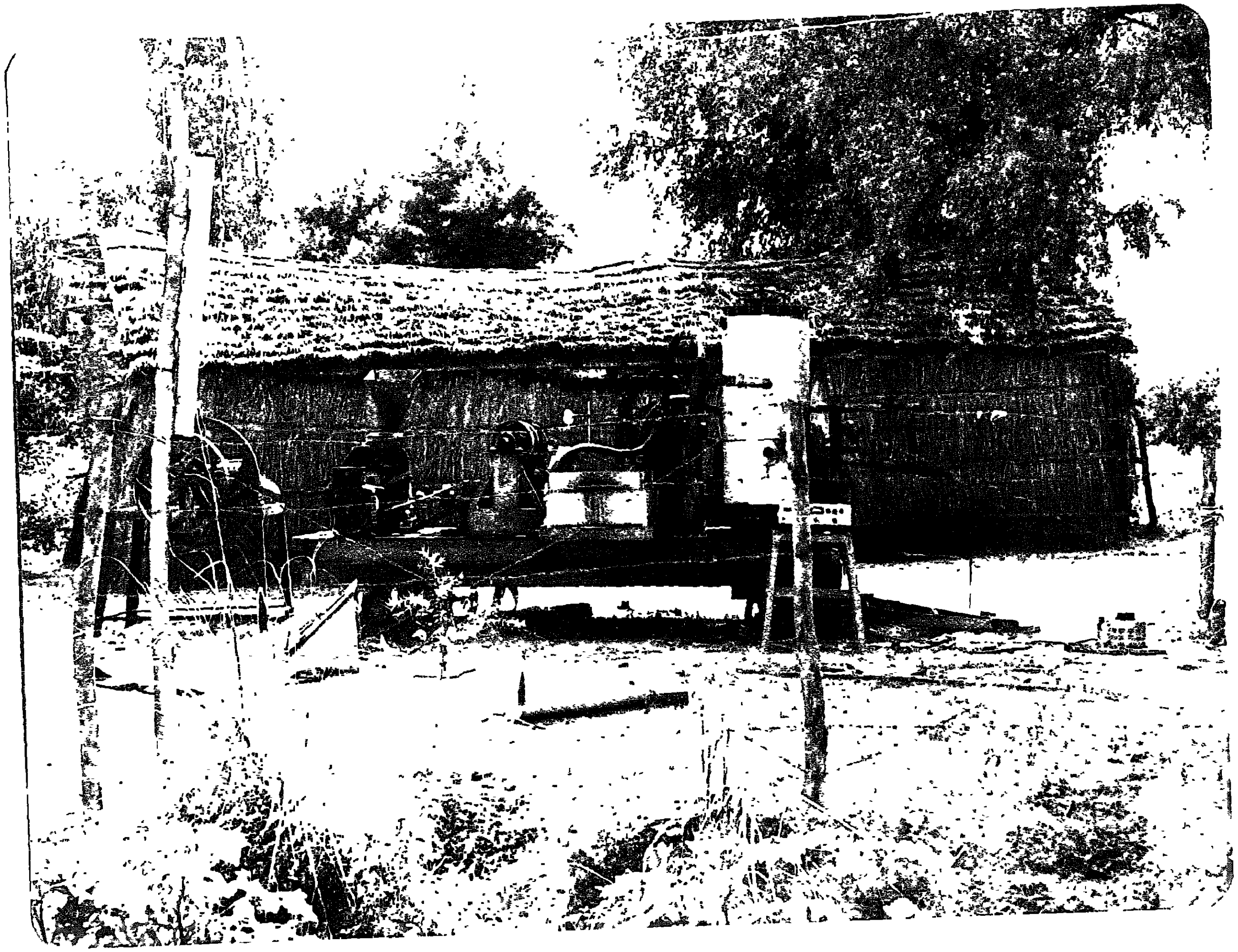


Figure 9.19 : Another view of the unit installed at the village site.

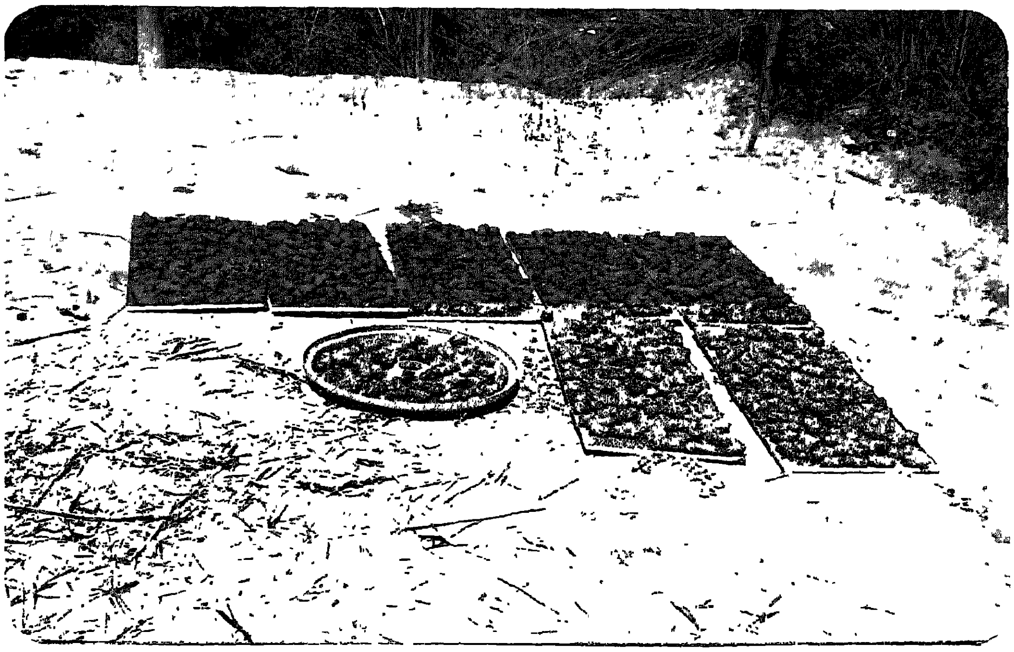


Figure 9.20 : The briquettes kept for sun drying.

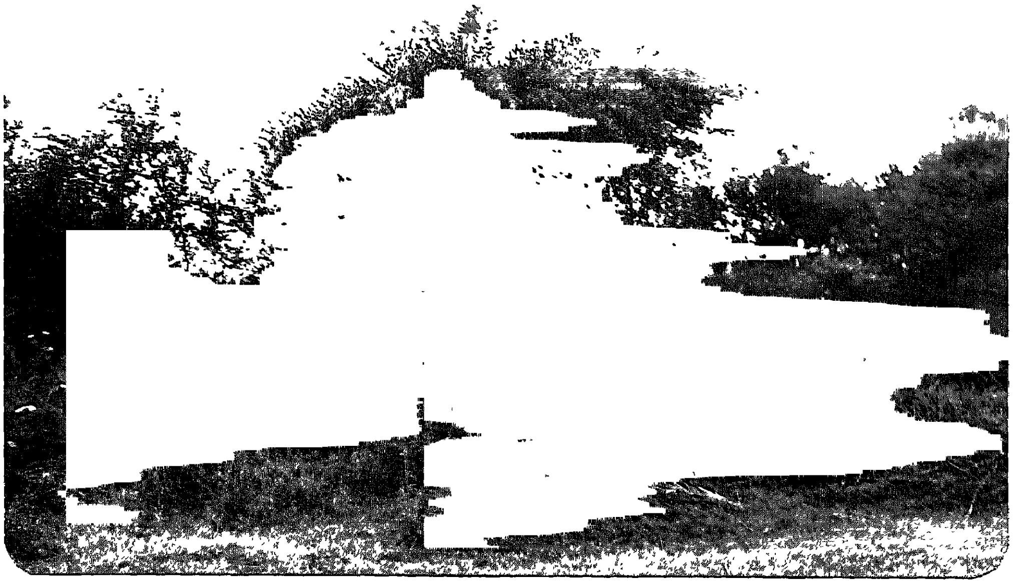


Figure 9.21 : Mustard stalk available in the village.

Testing on the first prototype, as described earlier, showed high quantities of particulate matter in the gases obtained from low density briquettes. In order to eliminate this problem, a cyclone filter, details of which are shown in fig. 9.9, had been fabricated and installed at the exit point of the gases from the gasifier.

The design and dimensions of the cooler cum tar seperator are same as for the first prototype. Only, for increased time of contact between the gases and cold surfaces, a series of baffles have been added, as shown in fig. 9.10.

The design of the dust seperator was also simplified as shown in fig. 9.11.

The briquetting machine, details of which are shown in fig. 9.12, was fabricated from a local workshop and was not purchased. This machine differs from the commercially available one (described in section-6), the differences being listed below.

i) The gap between the worm and the walls is much smaller

ii) The design of the hopper is different

iii) Ball bearings instead of bush bearings are used in the present design

iv) A 7:1 speed reduction gear is used in the present design instead of the large diameter pulley employed for the commercial machine. This resulted in a more compact arrangement.

A close view of the briquetting machine on the trolley is shown in fig. 9.13.

The pulverizing machine mounted on the trolley, shown in fig. 9.14, was procured locally. Figure 9.15 shows a close up of the alternator on the field prototype. A Hero-Honda speedometer was also installed on the prototype as shown in fig. 9.16. The speedometer reading is proportional to the rpm of the engine and the counter reading is proportional to hours of operation. Both have been calibrated so that the device can be used as an hour meter.

A top view of the field prototype unit on the trolly before it was taken to the village is shown in fig. 9.17. The view of the unit as installed at the village site is shown in figs. 9.18 and 9.19. The hut shown in the background in fig 9.19 has been constructed for storing briquettes. The briquettes kept for sun drying are shown in fig 9.20 and a portion of the mustard stalks available in the village are shown in fig. 9.21.

9.4 Performance of the field prototype :

Detailed temperature profiles could not be obtained for the first prototype gasifier, but this task had been accomplished to some extent in the second prototype. The main problem was the selection of proper temperature sensor.

Several probes tried earlier melted away due to the high temperatures in the fire box. Finally a J-type thermocouple with porcelain and S.S sheathing was employed with some success. The thermocouple is not accurate for temperatures above 1200°C, but in the range 1200°C and above, high accuracy was deemed unnecessary. The temperature history at the centre of the fire box during start-up and after shut-down are shown in figs 9.22 and 9.23 respectively. The fast rise during start-up and the slow decay during shut-down indicate the effectiveness of the insulation. The radial temperature profile for low, medium and high gas production rates are shown in figs 9.24-9.26 for wood chips. The radial temperature profile for high gas production rate (mustard stalk briquettes) at the design gas production rate is shown in fig. 9.27. It is apparent that the profiles become flatter at high gas flow rates, indicating that near-plugflow conditions are achieved at higher flow rates. The vertical temperature profile in the gasifier is shown in fig. 9.28.

Gas composition, tar, dust and moisture contents and biomass flow rates could not be measured due to lack of time. The pressure drops across the various components of the gasifier system are as follows :

ΔP across cyclone seperator : 10 mm WG
ΔP across cooler : 7 mm WG
ΔP across dust filter : 25 mm WG

The diesel consumption values in diesel mode and dual-fuel mode (with briquetted mustard stalk) are shown in

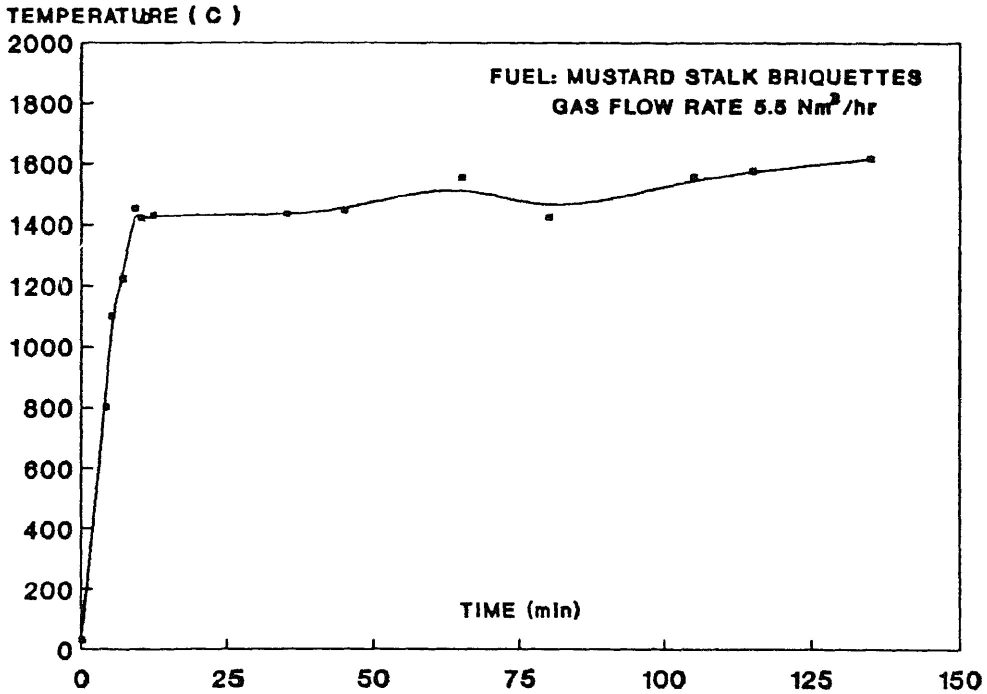


Figure 9.22 : Temperature history at the centre of the fire box during start up

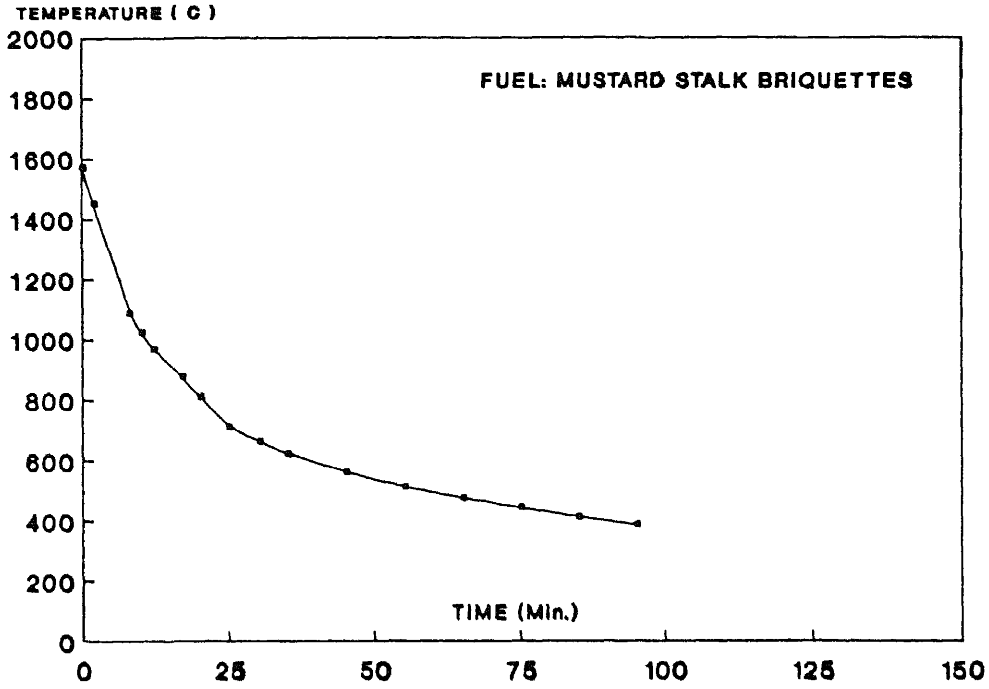


Figure 9.23 : Temperature history at the centre of the fire box after shut down

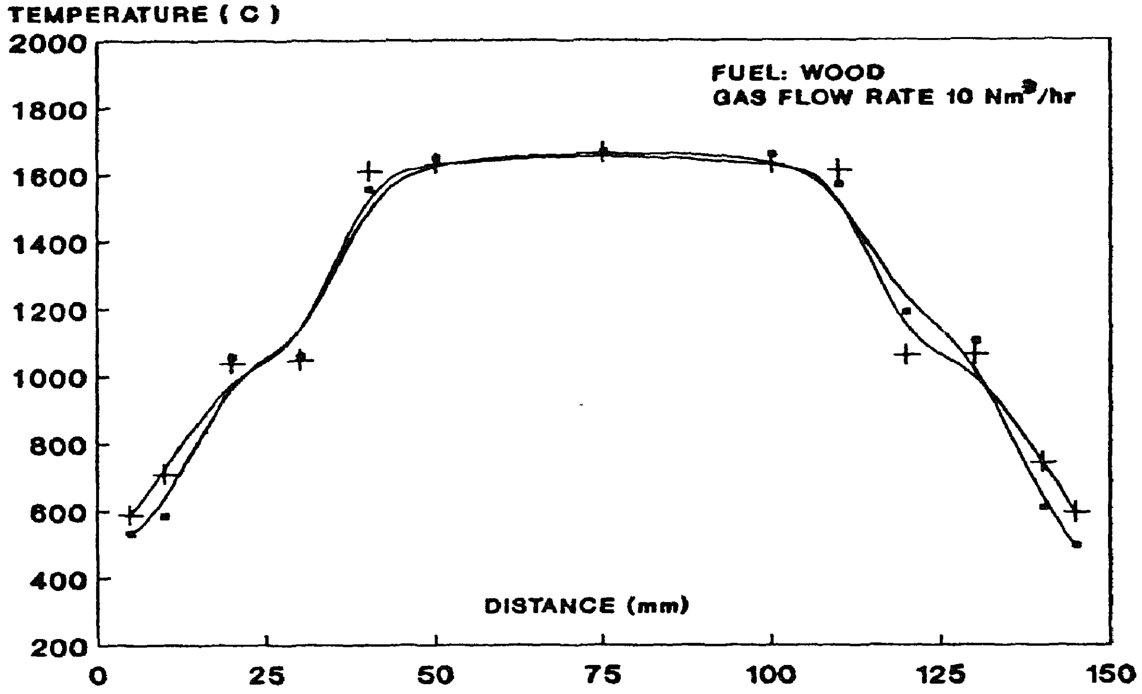


Figure 9.24 : Radial temperature profile for low gas production rate (fire wood)

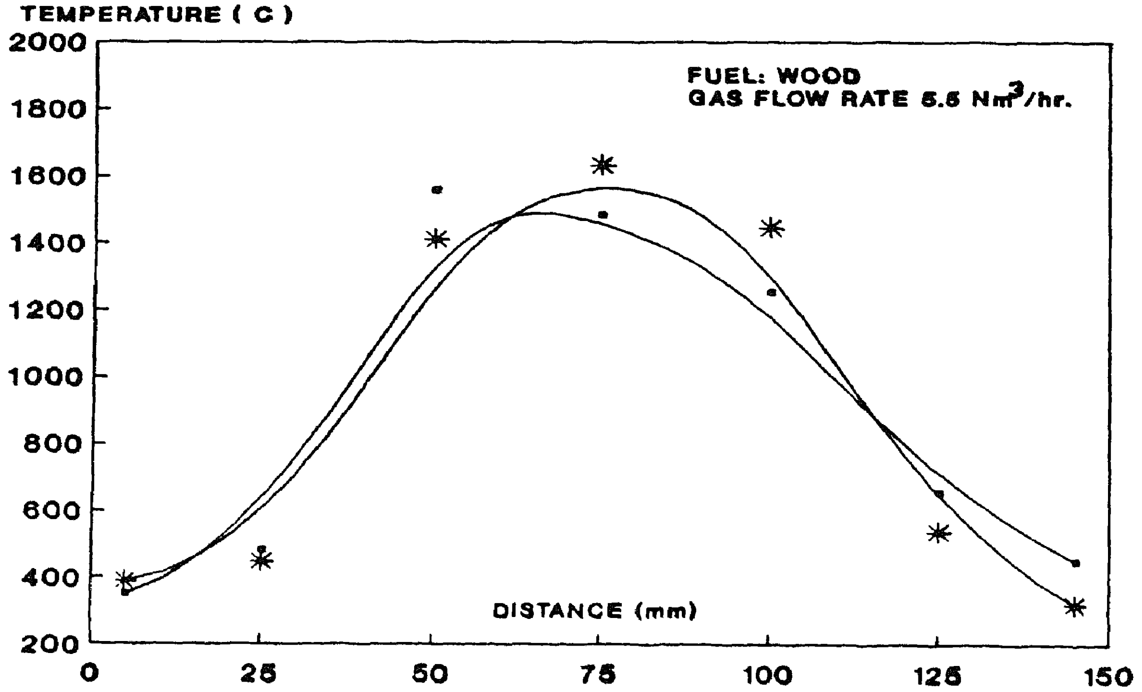


Figure 9.25 : Radial temperature profile for medium gas production rate (fire wood)

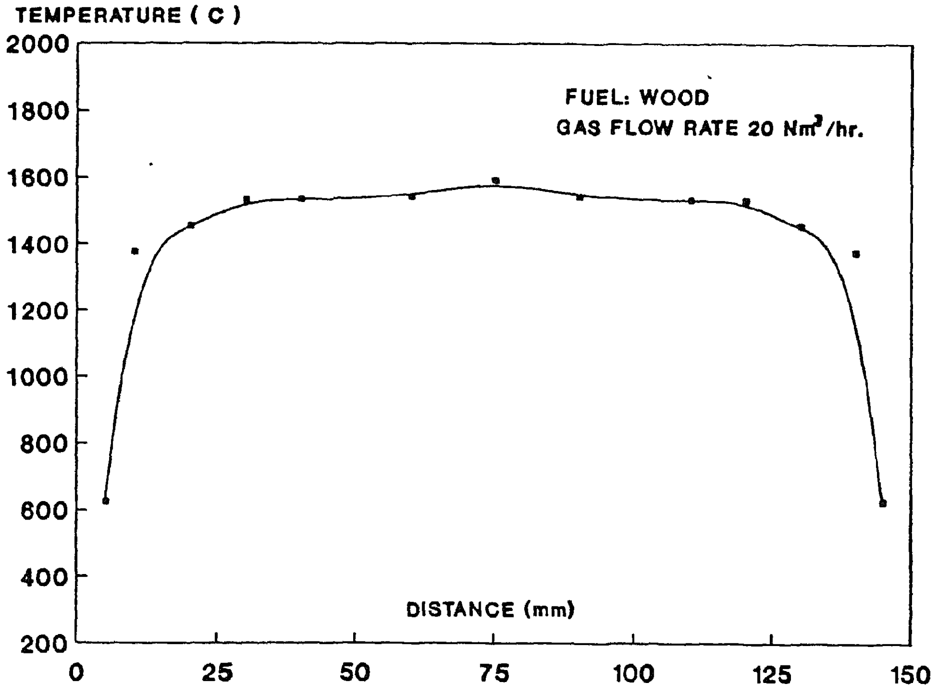


Figure 9.26 : Radial temperature profile for high gas production rate (fire wood)

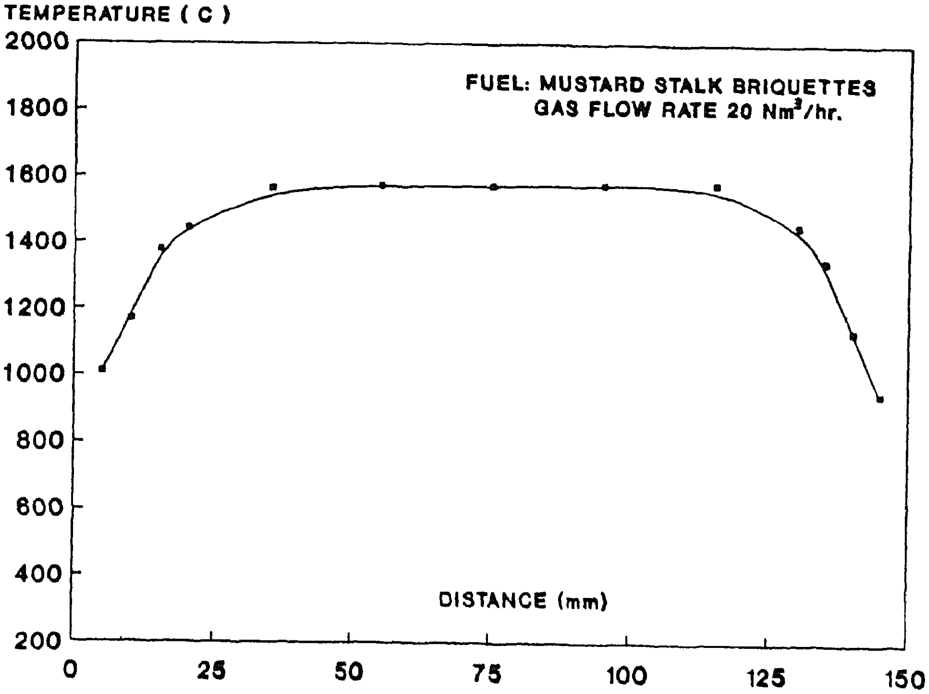


Figure 9.27 : Radial temperature profile for high gas production rate (mustard stalk briquettes)

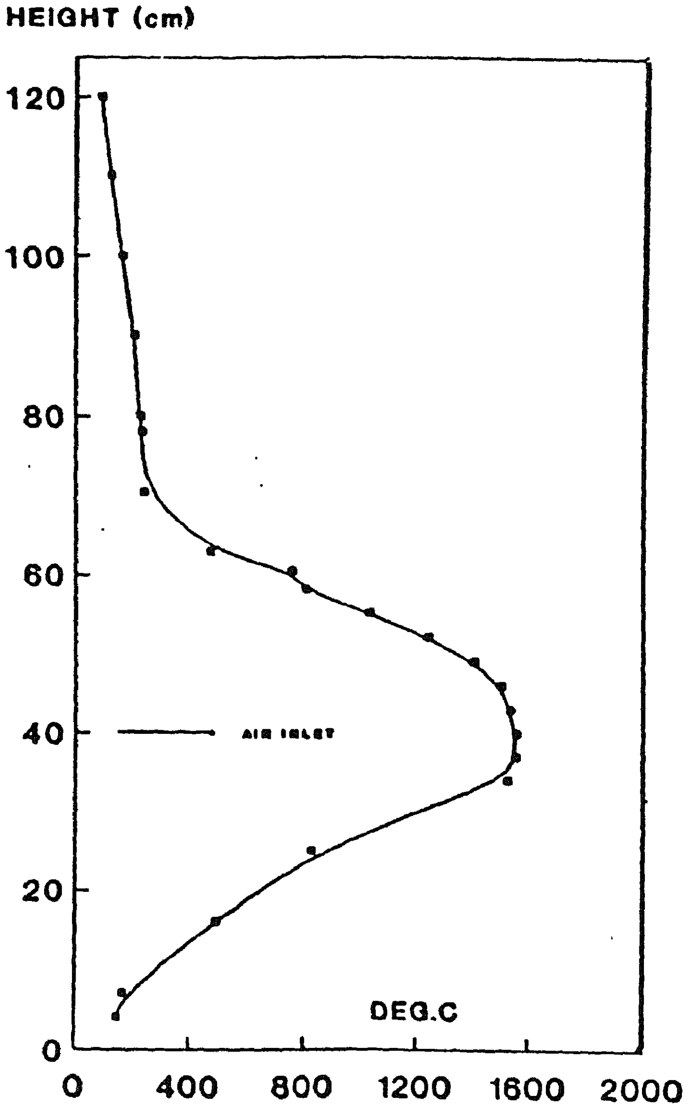


Figure 9.28 : Vertical temperature profile in the gasifier

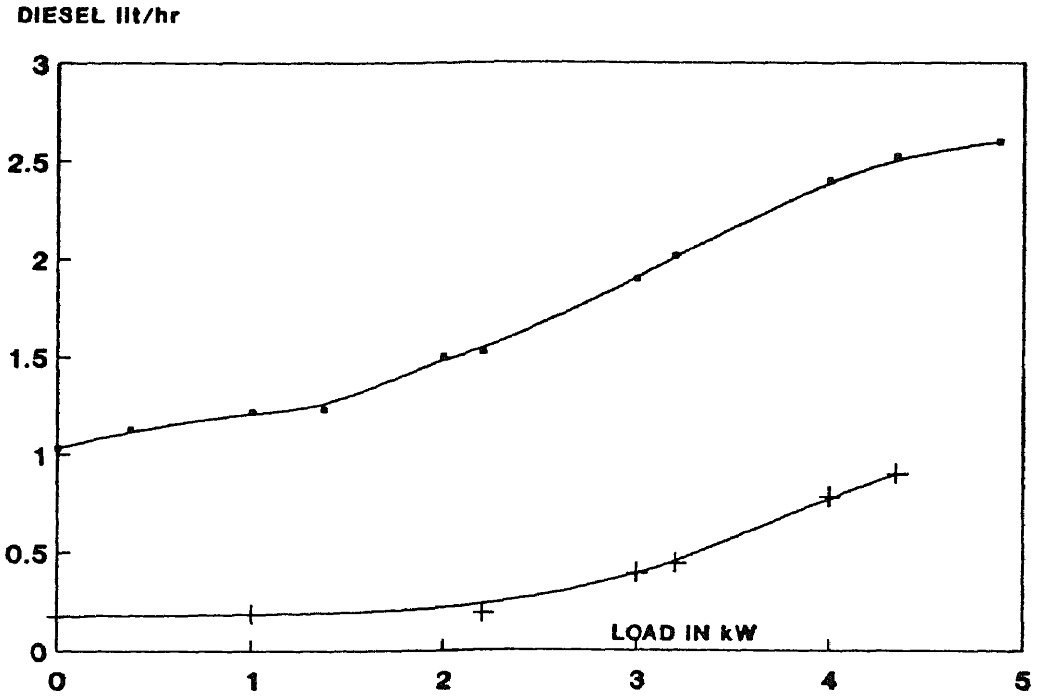


Figure 9.29 : Diesel consumption values in diesel mode and dual fuel mode

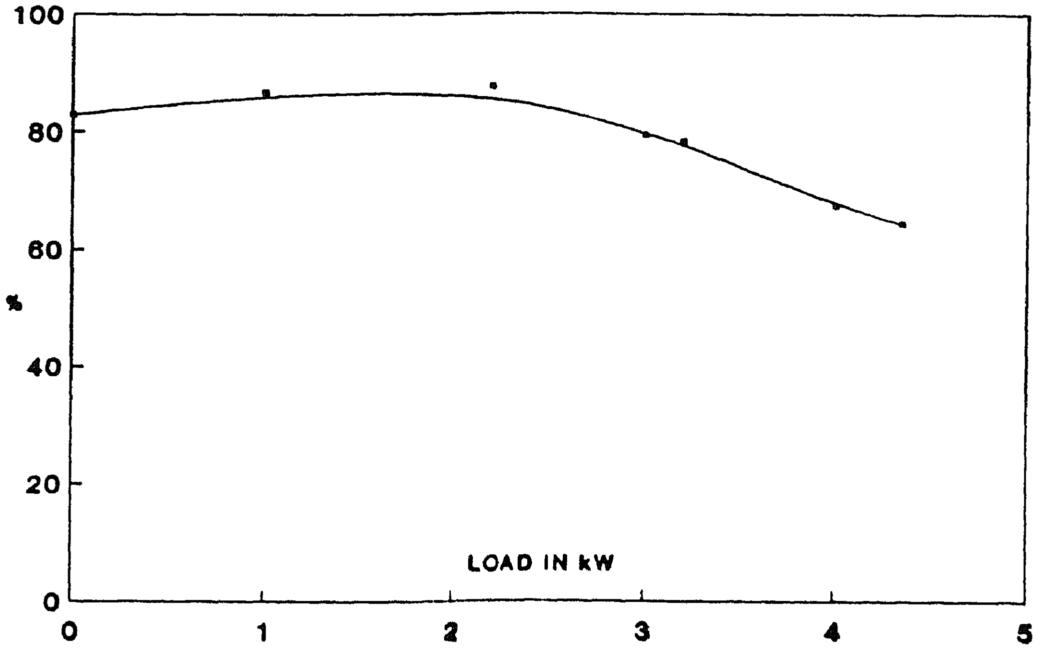


Figure 9.30 : Percentage of diesel replacement at different loads

fig. 9.29 as functions of load. The percentage of diesel replacement at different loads are shown in fig. 9.30. Due to the improved design of the gasifier, it can be seen that higher diesel replacements of the order of 80% could be achieved. The diesel replacement, however, decreases to about 65% at higher load. This behaviour is consistent with that for dual-fuel operation reported by earlier workers.

Detailed measurements of parameters such as rate of production, diesel consumption in 100% diesel mode and diesel consumption is dual-fuel mode, were obtained for each of the processes of chopping, pulverising and briquetting. The summary of these measurements is shown in Table 9.2. It can be seen that the specific diesel consumption in dual-fuel mode for conversion of stalks into briquettes is as low as 0.007 lit/kg (dry briquettes). At a diesel price of 4 Rs/lit, the cost of processing mustard stalks into briquettes works out to just 3 paise/kg. The energy consumption figures reported here are lesser compared to commercial briquetting machines. This is perhaps because of the low density of briquettes obtained requiring low energy inputs.

Table 9.2 : Parameters for processing mustard stalk to gasifier fuel

Process/ Parameter	Chopping	Pulverising	Briquetting	Cutting with circular saw
Bulk density after the process (kg/m^3)	94	219	268	79
Rate of processing (kg/hr)	110	73	163	20
Diesel consumption, lit/hr				
Diesel mode	.783	1.058	0.783	1.050
Dual fual mode	.196	0.312	0.196	0.262
Specific diesel Consumption, lit/kg				
Diesel mode	0.00712	0.01449	0.0048	0.0131
Dual fuel mode	0.00178	0.00427	0.0012	0.00328

The system has logged about 400 hrs till September 1990, out of which 200 hrs were in laboratory and 200 hrs were in the field.

9.5 Economic considerations :

The cost details of the system are shown in Table 9.3. The total cost of the system is about Rs. 70,000 (1989 prices). The overall economics of the system will depend on the particular end use (5). Though the original objective of the project was to develop a non-wood biomass gasifier system for irrigation pumping, the system which finally evolved was a multipurpose one, and the capacity of the system had to be increased also, mainly due to technology constraints. As outlined in section 2, restricting the utility of the system for only irrigation pumping would not be economically viable. No attempt has been made here to assess the economic viability of the briquetting-gasification system developed in this project for a privately owned irrigation pumping application as it is thought to be a futile exercise. However, due to the fuel-flexibility and end-use flexibility, the system promises to have a significant potential for other modes of utilisation as described in the next section.

Table 9.3 : Cost details of the system

Trolly for assembling the system	Rs. 14,000.00
Gasifier	Rs. 10,000.00
Cyclone filter	Rs. 500.00
Gas cooler	Rs. 3,000.00
Dust filter	Rs. 500.00
Grate shaking unit	Rs. 2,000.00
Gas distribution line (Pipes & fitting, Valves etc.)	Rs. 2,000.00
Blower for Ignition	Rs. 1,000.00
Common shaft, pulleys bearing etc.	Rs. 4,000.00
Alternator (7KVA)	Rs. 6,000.00
Diesel Engine (10 H.P.)	Rs. 6,000.00
Pulveriser	Rs. 5,000.00
Briquetting machine	Rs. 5,000.00
Chopper	Rs. 2,000.00
Assembling charges	Rs. 3,000.00
	Rs. 64,000.00
Miscellaneous	Rs. 6,000.00
Total	Rs. 70,000.00

10. POTENTIAL APPLICATIONS OF THE BRIQUETTING -GASIFICATION SYSTEM

Several 'modes' of utilising the system developed in this project could be envisaged, as outlined below.

10.1 The system as a biomass-based decentralised power station for rural electricity generation :

The main problems for any biomass based electric power system were linked with i) availability of biomass and ii) availability of technology which can utilize several biomass residues. The availability of biomass is a larger issue, depending upon region, present uses of biomass etc. It would, however, be appropriate to state that several locations, with varying degrees of availability of biomass, could be identified in the country where utilisation of biomass for power generation is distinctly feasible. The residues which lend themselves for such an application are rice husk, cotton stalks, mustard stalks, jute sticks sugarcane leaves etc. The capacity of the power plant should however be in the range of 100-500 kW in order to have some impact. A preliminary economic analysis can be carried out as shown below, for the particular end use of electricity generation.

The capital cost of the briquetting-gasification system prototype is about Rs. 10,000 per kW. Including infrastructure costs such as a shed for storage of briquettes would increase the cost, but this would be off set for higher capacity systems, as the system cost per kW would be lower at higher capacities. The levelised annual cost of electricity (LAC) can be written as

$$LAC = \frac{(CRF + OMR)\, C_S}{N} + M_B C_B + M_D C_D$$

where, C_S is the capital cost per kW, CRF is the capital recovery factor defined in section 2, OMR is the operation, maintenance and repair cost, usually taken as a fraction of the capital cost, M_B is the consumption of biomass per kWh (net), C_B is the cost of biomass, M_D is the specific diesel consumption in lit/kWh (net), C_D is the cost of diesel in Rs/lit and N is the total number of kWh (net) delivered by the system per kW.

For each kWh generated, the consumption of briquettes would be about 1.2 kg. There is a further 'self-consumption' of briquettes to produce briquettes, of the order of 0.15 kg/kg, hence the total amount of biomass needed, (M_B) would be 1.15 x 1.2, i.e., 1.38 kg/kWh (net). The specific diesel consumption in dual fuel mode can be taken as 0.15 lit/kWh. The diesel consumption for production of briquettes is about 0.007 lit/kg (Table 9.2), and as 1.38 kg of briquettes are needed to produce 1 kWh, the diesel consumption for briquetting would be $0.007 \times 1.38 \simeq 0.01$ lit/kWh (net). The total diesel consumption (M_D) is thus 0.16 lit/kWh. The LAC can then be written as

$$LAC = \frac{(CRF + OMR)}{N} \times C_S + 1.38\, C_B + 0.16\, C_D$$

$$= \frac{(CRF + OMR) \times C_S}{LF \times 8760} + 1.38\, C_B + 0.16\, C_D$$

where, LF is the load factor. The following assumptions have been made for evaluating a typical LAC

$CRF = 0.147$ at 12% discount rate and 15 yr life

$OMR = 0.1$

$C_S = 10,000$ Rs/kW

$LF = 0.333$ (8 hrs per day)

$C_B = 0.1$ Re/kg

$C_D = 4$ Re/lit

For the above conditions, the LAC is obtained as

$$LAC = \underset{\substack{\text{(interest}\\ \text{\& OMR)}}}{0.847} + \underset{\text{(biomass)}}{0.138} + \underset{\text{(diesel)}}{0.64}$$

$$= 1.625 \text{ Rs/kWh}$$

The above value is consistent with the range of values obtained in an earlier study [41] for biomass based power systems. The cost of electricity can be significantly reduced by technology improvements by way of reducing capital costs and specific fuel consumptions. The cost of diesel electricity would roughly be 2.00 Rs/kWh. It can thus be seen that the system is potentially suitable for power generation in rural areas.

10.2 The system as a gasifier-operated briquetting plant :

Several studies have been done in the past to prove the economic viability of briquetting biomass. The main hurdles for briquetting technology seemed to be i) high operational costs and ii) lack of market for briquettes. As the present system generates its own motive power at a cost lower than industrial electricity tariffs, the cost of production of briquettes can be lower. Applying the same formula for LAC as given in the last sub section, the cost of briquettes can be obtained as

$$LAC = \frac{(CRF + OMR) \times C_S}{N} + 1.15\ C_B + 0.0115\ C_D$$

In the above equation C_S is the capital cost of the system and N is the amount of briquettes produced per year. As mentioned in Section 6, there exists a correlation between the output rate of the briquetting machine and the power. For an available power of 100 kW, the output of briquetting machine has been estimated to be about 2000 kg/hr. Unlike the generation and consumption of electricity, briquettes can be made and stored and hence there are no constraints on the capacity utilisation of the briquetting machine other than those related to the supply of biomass. Assuming an 8 hr operation for 200 days, which is on the lower side, the LAC is calculated as

$$LAC = \underset{\text{(interest \& OMR)}}{0.077} + \underset{\text{(biomass)}}{0.115} + \underset{\text{(diesel)}}{0.046}$$

This is a very attractive figure and even considering an increased cost of biomass, the cost of briquettes could be much less than wood chips.

A situation can be visualised in which there is a centralised facility in a village where farmers can bring their biomass, pay for the extra charges of briquetting and collect an equal amount of briquettes. In this way several privately owned, individually operated gasifier pumping systems can be realised. As the cost of briquettes is less, operation of the gasifier system would be more economical than 100% diesel operation.

A second possibility is to produce charcoal-like material from briquettes (biocoal) which in principle has the capacity to penetrate the charcoal market. As the cost of charcoal is very high at present, the whole venture could be made profitable. Installation of a large capacity briquetting-gasification system can thus open up several possibilities of biomass utilisation and income generation.

10.3 The briquetting-gasification system as an oil-saver for industry :

Residues such as saw dust, groundnut shell, bamboo dust (from paper mills) etc. can be briquetted and gasified in-situ, and the gas can be used either in oil fired boilers or in diesel gensets, saving fuel oil or diesel respectively. An an example, while making routine energy audits, the Industrial Energy Group of TERI came to know that Dabur India Ltd. produces a herbal waste to the tune of 7 tons/day. Briquettes of this waste were successfully gasified in the field prototype. Preliminary calculations of economic viability of a briquetting-gasification system for Dabur India Ltd. indicated a pay back period of about 1½ years, which is very attractive for the industry. Similar enquiries have also been received from ITC and Brooke-Bond India Ltd.

The main hitch in propularising this system in the industry is that there may not be any precedents and the technology is as such untested on a scale which would attract the attention of the industrial concerns.

11. CONCLUSIONS

A prototype briquetting-gasification system, with both fuel and end-use flexibility has been developed. The system consists of a gasifier, with associated cooling and cleaning train, a chopper, a pulveriser, a briquetting machine, a diesel generator and an alternator. The gasifier is a throatless type with a low specific gasification rate and with mechanism for continuous ash removal. The cooling and cleaning train is simple and yet effective and does not require continuous supply of water. The processing of biomass involves chopping, pulverising and briquetting in a screw-extruder after adding dung or biogas plant effluent as binder. The air dried briquettes are then gasified and the gases used in a diesel engine in a dual fuel mode. All the operations mentioned above do not need external source of power, and are performed by the gasifier - driven diesel engine.

Several residues such as saw dust, mustard stalk, bajra stalk, groundnet shell etc. had been successfully used, in briquetted form, to run the gasifier. The chemical composition of the gases, and the level of contaminants (tar and dust) are within acceptable limits to run an internal combustion engine. Diesel replacements of 60-80% have been achieved.

The overall system concept and configuration had been achieved by a process of extensive trials, in which several devices performing different functions had been assembled in an optimal fashion. The briquetting-gasification system has a significant potential for exploitation of several biomass residues and can be used for i) power generation ii) production of briquettes or biocoal for rural or urban consumption and iii) industrial applications.

The scale, however, is an important factor for deciding the economic viability. For the applications mentioned above, a size of 100 kW_e and above seems to be desirable from both technology and economic considerations.

REFERENCES

1. "Design, fabrication, testing and field demonstration of biomass gasifier system for irrigation pumping", proposal submitted to the Department of Non-conventional Energy Sources, Ministry of Energy, Govt. of India, New Delhi by Tata Energy Research Institute (1986).

2. V.V.N. Kishore, "Economics of Wood Gasifier Systems for Irrigation Pumping", Ind. J. of Agric. Econ. Vol. 44 No. 1, Jan-Mar (1989).

3. T.B. Reed (ed.), Biomass Gasification-Principles and Technology, Noyes Data Corporation, New Jersey, USA (1981).

4. A. Kaupp and J.R. Goss, Small Scale Gas Producer-Engine Systems, GTZ/GATE publication, 1984.

5. A. Kaupp, Gasification of rice hulls, GTZ/GATE publication, 1984.

6. Final report of the project "Energy Agriculture" and the first report of the School of Energy Studies for Agriculture, Punjab Agricultural University, Ludhiana, 1985.

7. Development and field testing of small biomass gasifier-engine systems in India - A joint project of an American and Indian team, the MITRE Corporation, April 1987.

8. Annual Progress report on Development of fluid bed rice husk combustor/gasifier, Bharathidasan School of Energy, Bharathidasan University, Tiruchirapalli, 1988.

9. S.Kohli, P.Raman and V.V.N. Kishore, "Evaluation of various fuels for gasification," Proceedings of the National Solar Energy Convention held at I.I.T., Delhi, Dec. 1987.

10. Thermo-chemical characterisation of biomass for gasification", BIomass Conversion Laboratory, Chemical Engineering Department, I.I.T., Delhi, 1988.

11. "Biomass-Thermochemical characterisation for gasification, (ed) P.D. Grover, I.I.T., Delhi, 1989.

12. S. Gaur et al, 'Development and operation of a biomass gasification system for 5 hp irrigation pumps, paper presented at the 3rd annual workshop on biomass and coal conversion programmes of the USAID-GOI project, held in New Delhi, Dec. 1985.

13. B.M. Jenkins, Downdraft gasification characteristics of major California residue-derived fuels', Ph.D. Dissertation 1980.

14. M.P. Sharma and B. Prasad, Development of a downdraft biomass gasifier for thermal and power generation applications, Energy Management, Oct-Dec 1986.

15. Anil Rajvanshi and Manasi Joshi, Development of a small (3-5 kW) gasifier for rural water pumping applications, paper presented at the 3rd conference of Bio-Energy Society of India, Pune, 1986.

16. P.P. Parikh, A.G. Bhave, D.V. Kapse, A. Ketkar and A.P. Bhagwat, Design and Development of a wood gasifier for I.C. engine applications - New approach for minimisation of tar, I.I.T. Bombay. (pre-print)

17. S. Dasappa, U. Shrinivasa, B.N. Baliga and H.S. Mukunda, Five kilowatt wood gasifier technology : Evolution and field experience, Sadhana, Vol. 14, part 3, pp. 187-212 (1989).

18. M.J. Groeneveld, P.E. Gellings, and J.J. Hos, Production of a tar-fire gas in an annular co-current moving bed gasifier, Energy from Biomass and Wastes VII : Symposium papers, Lake Buena Vista, Florida pp. 433-454, (1983).

19. W.P. Walawender, S. Chern and L.P. Fan; Wood chip gasification in a commercial down-draft gasifier; Fundamentals of Thermo chemical Biomass Conversion, London, Elsevier Applied Science, pp. 911-922 (1985).

20. Jin-Shi Chen and Wesley W. Gunkel, Modelling and Simulatin of Co-current moving bed gasification reactors - Part II, A detailed gasifier model, Biomass Vol. 14 pp. 75-98 (1987).

21. P. Schlapfer, J. Tobler, Theortische und praktische Untersuchungen uber den Betrieb von Motorfahrzengen mit Holzgas, Bern (1937).

22. Jan Venselaar, "Design rules for downdraft wood gasifiers". Twente University, Project JTA-9A-Research Development, 1982.

23. Ulrich Graf, Design rules for downdraft gasifiers, GATE (1983).

24. Thomas B. Reed and Agua Das, Handbook of Biomass Downdraft gasifier engine Systems, SERI/SP-271-3022, March 1988.

25. Vincent and Marie-Sabine Damour, Development of Small scale gasifiers for irrigation purpose in India, 1983.

26. R.N. Pandya, K.C. Shah and M.B. Durgaprasad, Development of wood gasifier and gas cleanup system for irrigation, JSEI, Vallabh Vidyanagar.

27. GM55 Gasifier engine pumpset system - Instruction Manual, SPRERI.

28. U. Shrinivasa and H.S. Mukunda, Wood gas generators for small power (~5hp) requirements, Sadhana, Vol 7 part 2, pp 137-154, 1984.

29. S. Dasappa, Vikram Reddy, H.S. Mukunda and U. Shrinivasa, Experience with Gasifiers for 3.7 kW engines, Ambio, Vol. 14 No. 4-5, pp. 275-279, 1985.

30. Gumz W, Gas Producers and Blast Furnaces, Theory and methods of Calculation, John Wiley and Sons Inc., New York, 1950.

31. Groeneveld, M.J., The Co-current Moving bed gasifier, Ph.D. thesis, Twente Univ. of Technology, The Netherlands, 1980.

32. Perry, R.H. and Chilton, C.H. (Eds.), Chemical Engineers' Handbook, 5th edition, McGraw-Hill New York, 1973.

33. John R. Goss, Gasifier design, paper presented at the National Workshop on Biomass Conversion Technology, PAU, Ludhiana, march 1986.

34. V.V.N. Kishore, M.V. Ramana and D.P. Rao, An experimental and theoratical study of a natural water cooler, Proceedings of the National Solar Energy Convention held at I.I.T. Bombay, pp. 482-488, 1979.

35. V.V.N. Kishore, M.R. Gandhi, N. Pathak and P. Jaboyedoff, A Solar water pump for lift irrigation, Final report of the work done under an Indo-Swiss collaborative project at CSMCRI, Bhavnagar, 1983.

36. Soren Eriksson and Mike Prior, Briquetting Biomass Wastes for Fuel, Summary report, SIDA, 1989.

37. Leif Liinanki, Description of a method for measurement of the tar content in producer gas, The Producer Gas Newsletter, No. 2, May 1985.

38. S.D. Sharma, P. Raman and V.v.N. Kishore, Standardisation of an apparatus for the estimation of tar, particulate and moisture contents in producer gas, Proceedings of the 1st National meet on Recent Advances in Biomass Gasification Technology, pp 198-206, 1989.

39. S.D. Sharma and V.V.N. Kishore, Evaluation of performance of an apparatus for the estimation of tar, particulate and moisture contents in producer gas - unpublished report.

40. V.L.N. Murthy and V.V.N. Kishore, Modelling of Pyrolysis zone in a down draft biomass gasifier, Proceedings of the 1st National Meet on Recent Advances in Biomass Gasification Technology 1989.

41. K.S. Rao, V.V.N. Kishore and N.K. Bansal (eds.); *Technoeconomics of Renewable Energy Power Generating Systems*, Chapter 11, Sarita Prakashan, New Delhi.

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APPENDIX

(Copies of papers published on the basis of work done in the project)

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ECONOMICS OF WOOD GASIFIER SYSTEMS FOR IRRIGATION PUMPING

INTRODUCTION

Small sized wood gasifiers coupled to diesel pumps (3-7 HP) for irrigation pumping are considered to be potential devices for diesel oil saving. Diesel replacements upto 88 per cent had been claimed in laboratory experiments (Damour, 1983). Diesel replacement value under field conditions was reported to be about 60 per cent (Durgaprasad *et al.*, 1985). Wood gasifier systems are commercially being manufactured in India by a few companies. The Department of Non-Conventional Energy Sources (DNES) had initiated a programme of setting up demonstration units of gasifier systems throughout the country with a view to establishing the viability of these systems under field conditions. The technical problems associated with the gasifier systems are reasonably well-known and are being researched further. However, the economic viability of the systems either at present or in the near future has not been studied in detail. Considering the facts that the gasifier systems are expensive and that wood is becoming a scarce fuel in many parts of the country, it might be desirable to carry out a detailed study of the economics of gasifier-based irrigation pumping systems. The present note uses the technique of Life Cycle Costing (LCC) to analyse the economic feasibility of wood gasifier systems for irrigation pumping in comparison with conventional diesel operated pumpsets.

METHOD OF ANALYSIS

There are several indices like cost-benefit ratio, internal rate of return (IRR), pay back period, etc., to compare between alternative means for the same end use. The Levelised Annual Cost (LAC) is one such index which provides a relatively simple means of estimating the impact of different techno-economic options on apparent relative costs. The LAC approach is equivalent to the Net Present Value (NPV) approach in which each of the cash flows is determined and discounted to a present value. The LAC is defined as

$$\text{LAC} = \frac{\text{Annual cost}}{\text{Annual energy output}} \qquad \text{....(1)}$$

where

$$\begin{aligned}\text{Annualised cost} = {} & \text{Capital investment} \times \text{CRF} \\ & + \text{annual operation, maintenance and repair costs} \\ & + \text{annual fuel costs}\end{aligned}$$

The annual energy output for the pumping systems is proportional to the total amount of water pumped in m^3/year for a given system.

The capital recovery factor (CRF) converts the initial capital investment into a series of equal annual charges which have the same NPV. While dealing with economic (as distinct from financial) analysis, the CRF is a function of the economic discount rate (or the marginal return on capital) and the system life time, and can be obtained from the equation

$$CRF = r/1-(1+r)^{-OL} \quad \text{....(2)}$$

where r is the annual discount rate and OL is the operating life of the system.

We take a 5 HP diesel pumpset as basis for calculations. A specific diesel consumption of 0.235 litres/(HP)(hr), which is typical for small systems is assumed. The annualised cost for this system is given by

$$AC_1 = I_1 \times CRF_1 + OMR_1 + 0.235 \times 5 \times N \times C_d \quad \text{.... (3)}$$

where AC is the annualised cost, I is the capital investment, OMR is the annual operation, maintenance and repair cost, N is the number of hours of operation in an year and C_d is the cost of diesel fuel in Rs./litre. Subscript 1 denotes the conventional system. The annual output, W_1 will depend, besides other parameters, on the capacity of the system and the operating hours, and can be written as

$$W_1 = k \times 5 \times N \quad \text{.... (4)}$$

where k is a proportionality constant depending on total head, friction losses, etc. The LAC is then given by

$$\begin{aligned} LAC_1 &= AC_1/W_1 \\ &= (I_1 \times CRF_1 + OMR_1 + 1.175 N C_d)/5 kN \end{aligned} \quad \text{.... (5)}$$

A 5 HP gasifier coupled diesel pumpset would consume less diesel, and the reduced consumption is usually characterised by a 'diesel replacement value', expressed as a percentage or a fraction. The annual diesel consumption can then be expressed as 1.175 (1-DR)N, where DR is the diesel replacement in fractional terms. Thus for a 60 per cent diesel replacement, the value of DR would be 0.6. Besides diesel, wood is also consumed at a rate dependent on the efficiency of gasification. If we take the gasifier efficiency as 70 per cent, calorific value of wood as 4,000 kcal/kg., calorific value of producer gas as 1,100 kcal/Nm^3 and a gas consumption figure of 10 Nm^3/hr for a 5 HP system, the wood consumption figure can be calculated as 3.93 kg./hr. The annual wood consumption would then be equal to 3.93 N. The annualised cost for the gasifier system, denoted by subscript 2, can be written as

$$AC_2 = I_2 \times CRF_2 + OMR_2 + 1.175(1-DR)N\ C_d + 3.93\ N\ C_w \quad \text{.... (6)}$$

where C_w is the cost of wood in Rs./kg.

There is a certain amount of derating of engine capacity while operating in a dual fuel mode. The derating is lower for CI (compression ignition) systems and higher for SI (spark ignition) systems. As a result, the water delivered by a gasifier coupled diesel pump would be lower, provided the total head, frictional losses in pipes, etc., are the same as for system 1. The annual discharge for system 2 can be written as

$$W_2 = k(1-x) \cdot 5 \cdot N \qquad \text{.... (7)}$$

where x is the reduction (or derating) in the capacity expressed as a fraction. Typical derating figures of 10 to 20 per cent have been reported for gasifier coupled diesel engines. x would thus be typically 0.1 - 0.2. The LAC for system 2 can then be expressed as

$$\begin{aligned} LAC_2 &= \frac{AC_2}{W_2} \\ &= \frac{I_2 \times CRF_2 + OMR_2 + 1.175(1-DR)\,N\,C_d + 3.93\,N\,C_w}{k(1-x) \cdot 5 \cdot N} \qquad \text{.... (8)} \end{aligned}$$

The condition of economic viability can be expressed by the equation

$$LAC_2 \leq LAC_1 \qquad \text{.... (9)}$$

We define a factor f which is a ratio of LAC_2 to LAC_1. f is exactly equal to the ratio of net present value of costs of systems 2 and 1 for the same benefits and the condition of economic viability will then be expressed as

$$f \leq 1.0 \qquad \text{.... (10)}$$

The operating life of gasifiers is usually taken as ten years, whereas the diesel engine would have higher life time of about 15 years. We assume that the life of both systems 1 and 2 is the same at 15 years. As the discount rate will be the same for both systems, the CRF would thus be the same. The OMR costs for the gasifier system consist of three components, *viz.*, the OMR costs for diesel pump, OMR costs of gasifier and the cost of preparing wood chips from logs or bigger pieces. We assume that the OMR costs for diesel pump would be the same in both systems, although in many cases frequent breakdowns of engine have been reported for gasifier coupled engines. The costs of fuel preparation are directly proportional to the total amount of wood consumed. OMR_2 can thus be written as

$$OMR_2 = OMR_1 + OMR_g + y.\ 3.93\ N \qquad \text{.... (11)}$$

where y is the cost of cutting for 1 kg. of wood. If manual labour is used for cutting, then the local rate for labour should be taken for calculation and if an electric saw is used the cost of electricity should be taken.

With the above assumptions, an algebraic expression for f can be obtained as follows:

$$f = \frac{CRF \,.\, I_2 + OMR_1 + OMR_g + 1.175\,(1\text{-}DR)\,N\,C_d + 3.93\,N\,(C_w + y)}{(1\text{-}x)\,[CRF \,.\, I_1 + OMR_1 + 1.175\,N\,C_d]} \qquad \text{.... (12)}$$

It can be seen that f is a function of several parameters. In order to reduce the number of parameters, realistic values have been assigned for some of the parameters as follows: $DR = 0.7$; $x = 0.1$; $I_1 =$ Rs.7,000; $OMR_1 = OMR_g = 500$ Rs./year.
Equation (12) can now be expressed as

$$f = \frac{CRF.\, I_2 + 1{,}000 + 0.3525\,N\,C_d + 3.93\,N\,(C_w + y)}{(6300.\, CRF + 450 + 1.058\,N\,C_d)} \qquad \text{.... (13)}$$

RESULTS AND DISCUSSION

It can be seen from equation (13) that the main parameters affecting the economic viability function f are discount rate (r), capital cost of the gasifier pumping system (I_2), diesel price (C_d), number of hours of operation (N) and cost of wood chips ($C_w + y$). The discount rates considered in this paper are 0.12 and 0.09. The present cost of Rs.25,000 of the gasifier pump and a future possible cost of Rs.20,000 (for mass production) are taken for calculations. Three different diesel prices are considered: the present value of 3.5 Rs./litre, the value of 4.4 Rs./litre which includes a premium of 25 per cent accounting for scarcity of foreign exchange, and a value of 4.8 Rs./litre which represents a ten per cent increase in the diesel price. The cost of wood chips is varied from 0.2 - 1.0 Rs./litre and the number of hours of operation is varied from 500 - 3000 to account for regional variations. The variation of f with changes in the values of the parameters as above is shown in Tables I and II. Several conclusions are obvious from an examination of Tables I and II.

(1) For all the combinations of parameters considered, it is evident that gasifier based diesel pumps are economically not viable under the circumstances where $N \leq 2000$ hours *and* $(C_w + y) \geq 0.6$ Rs./kg.

(2) For $N \leq 1000$ hrs, the system is not viable at the present initial cost for *any* of the interest rates, diesel prices and wood chips prices considered in the study.

(3) For $(C_w + y) \geq 0.8$ Rs./kg., the system is not viable for *any* of the initial costs, discount rates, diesel prices and number of hours considered in the study.

For examining the viability of the gasifier system under real conditions, a detailed discussion on hours of operation and costs of wood chips is warranted.

For the particular end use of irrigation pumping, N depends on many factors like cropping pattern, cropping intensity, availability of alternate means of pumping, etc. The total number of hours of operation for electric pumpsets is available for various States of India (Government of India, 1983) and is shown in Table III. Similar data for diesel pumpsets are not available, but the data given in Table III can be taken as an upper limit for diesel pumps, because it is known that a significant number of diesel pumps are used as back-up devices due to non-availability of electricity (Ramesh and Thukral, 1988). The number of diesel pumps in each State has also been listed in Table III. To obtain an index of utilisation of diesel pumps, the total number of these pumps was divided by the total area irrigated by wells in a given State and tabulated. The hours of operation exceed 1000 only for the States of Haryana, Punjab, Rajasthan, Uttar Pradesh and Bihar and judging from conclusion (2) derived earlier, the feasibility of gasifier systems might be considered only for these States. It can be seen, however, from Tables I and II that for N ranging from 1000 to 2000 the system becomes viable for some combinations of discount rate, capital cost and diesel prices, *only* if the cost of wood chips is below 0.4 Re./kg.

TABLE I SENSITIVITY OF f FOR r = 0 12

N (hours)	$C_w + y$	0.2	0 4	0.6	0.8	1.0
I_z = 25,000 ; C_d = 3.5						
500		1.76	1.88	2.00	2.13	2.25
1000		1.32	1 47	1.63	1.78	1.94
1500		1.11	1.28	1.45	1.62	1 79
2000		0.99	1 17	1.35	1 53	1.71
2500		0 91	1.10	1.28	1.47	1 65
3000		0 86	1.05	1.24	1.43	1.62
I_z = 25,000 . C_d = 4.4						
500		1.58	1 68	1.79	1.90	2.00
1000		1.16	1.29	1.42	1.55	1.68
1500		0.98	1.12	1.26	1.40	1.54
2000		0.87	1 02	1.17	1.32	1.46
2500		0.81	0.96	1.11	1 26	1.41
3000		0.76	0.92	1.07	1.22	1.38
I_z = 25,000 ; C_d = 4.8						
500		1.51	1.61	1.71	1.81	1.91
1000		1.11	1.23	1.35	1 47	1.60
1500		0.93	1.06	1.20	1.33	1.46
2000		0.84	0.97	1.11	1 24	1.38
2500		0 77	0.91	1.05	1 19	1.33
3000		0 73	0.87	1.01	1 16	1.30
I_z = 20,000 ; C_d = 3.5						
500		1.53	1 66	1.78	1.90	2.02
1000		1.17	1 33	1.48	1.64	1.79
1500		1.01	1.18	1.35	1.52	1.69
2000		0.91	1.09	1.27	1.45	1.63
2500		0.85	1 03	1.22	1.40	1.59
3000		0.80	0 99	1.18	1.37	1.56
I_z = 20,000 ; C_d = 4.4						
500		1.38	1 49	1.59	1 70	1.80
1000		1 04	1.17	1.30	1.43	1.56
1500		0.89	1.03	1.17	1.31	1.46
2000		0.81	0 95	1.10	1.25	1.39
2500		0.75	0.90	1.05	1.20	1.36
3000		0 71	0.87	1.02	1.18	1.33
I_z = 20,000 ; Cd = 4.8						
500		1.32	1 42	1.52	1.62	1.72
1000		0.99	1 12	1.24	1.36	1.48
1500		0 85	0 98	1.11	1.24	1.38
2000		0.77	0 91	1.04	1.18	1.32
2500		0.72	0.86	1 00	1.14	1.28
3000		0.68	0.83	0.97	1.11	1.25

TABLE II. SENSITIVITY OF f FOR $r = 0.09$

N (hours)	$C_w + y$	0.2	0.4	0.6	0.8	1.0
				$L_s = 25{,}000$; $C_d = 3.5$		
500		1.66	1.79	1.91	2.04	2.17
1000		1.24	1.40	1.56	1.72	1.88
1500		1.05	1.23	1.40	1.57	1.75
2000		0.94	1.12	1.31	1.49	1.67
2500		0.87	1.06	1.25	1.44	1.62
3000		0.82	1.01	1.21	1.40	1.59
				$L_s = 25{,}000$; $C_d = 4.4$		
500		1.48	1.59	1.70	1.81	1.92
1000		1.09	1.23	1.36	1.49	1.63
1500		0.93	1.07	1.21	1.36	1.50
2000		0.83	0.98	1.13	1.28	1.43
2500		0.77	0.93	1.08	1.23	1.38
3000		0.73	0.89	1.04	1.20	1.35
				$L_s = 25{,}000$; $C_d = 4.8$		
500		1.42	1.52	1.63	1.73	1.83
1000		1.04	1.17	1.29	1.42	1.54
1500		0.88	1.02	1.15	1.28	1.42
2000		0.80	0.93	1.07	1.21	1.35
2500		0.74	0.88	1.02	1.16	1.30
3000		0.70	0.84	0.99	1.13	1.27
				$L_s = 20{,}000$; $C_d = 3.5$		
500		1.46	1.58	1.71	1.84	1.97
1000		1.12	1.27	1.43	1.59	1.75
1500		0.96	1.13	1.31	1.48	1.66
2000		0.87	1.05	1.24	1.42	1.60
2500		0.81	1.00	1.19	1.38	1.56
3000		0.77	0.96	1.16	1.35	1.54
				$L_s = 20{,}000$; $C_d = 4.4$		
500		1.31	1.42	1.53	1.64	1.75
1000		0.99	1.12	1.26	1.39	1.52
1500		0.85	0.99	1.14	1.28	1.43
2000		0.77	0.92	1.07	1.22	1.37
2500		0.72	0.88	1.03	1.18	1.34
3000		0.69	0.85	1.00	1.16	1.31
				$L_s = 20{,}000$; $Cd = 4.8$		
500		1.25	1.36	1.46	1.56	1.67
1000		0.94	1.07	1.19	1.32	1.44
1500		0.81	0.95	1.08	1.21	1.35
2000		0.74	0.88	1.02	1.16	1.29
2500		0.70	0.84	0.98	1.12	1.26
3000		0.66	0.81	0.95	1.09	1.24

TABLE III. INDICES SHOWING UTILISATION OF DIESEL PUMPSETS IN VARIOUS STATES

State	N (hours/year)	No. of diesel pumpsets* 1978-79	Net area irrigated by wells† ('000 ha.) (1982-83)	No. of diesel pumps per 1,000 ha.
Haryana	1086	70,000	1,090	64.2
Punjab	1636	2,68,000	2,080	128.8
Rajasthan	1081	58,000	1,997	29.0
Uttar Pradesh	1625	8,51,000	6,071	140.2
Gujarat	722	5,67,500	-	-
Madhya Pradesh	465	98,170	1,123	87.4
Maharashtra	888	2,14,470	-	-
Bihar	1298	1,33,000	855	155.6
Orissa	542	9,100	-	-
West Bengal	674	86,500	618	140.0
Andhra Pradesh	758	1,45,331	839	173.2
Karnataka	397	43,945	418	105.1
Kerala	277	26,649	-	-
Tamil Nadu	677	1,17,124	959	122.1

* *Source:* Indian Institute of Petroleum(1978).

† *Source:* Directorate of Economics and Statistics, Ministry of Agriculture, Government of India.

TABLE IV. RETAIL PRICES OF FIREWOOOD IN SELECTED CENTRES

(Rs. per kg.)

Month/Year	Calcutta	Delhi	Madras	Bangalore	Hyderabad
April 1978	0.35	0.35	0.32	0.23	0.25
April 1979	0.43	0.47	0.41	0.24	0.30
April 1980	0.48	0.48	0.48	0.34	0.31
April 1981	0.57	0.61	0.52	0.38	0.40
April 1982	0.66	0.71	0.55	0.45	0.49
April 1983	0.66	0.80	0.57	0.58	0.58
April 1984	0.68	0.96	0.66	0.59	0.65
April 1985	0.79	1.04	0.71	0.63	0.66
April 1986	0.98	1.20	0.72	0.70	0.70
April 1987	1.04	1.23	0.72	0.66	0.64

TABLE V. INDICES SHOWING THE AVAILABILITY/SCARCITY OF WOOD FOR GASIFICATION PURPOSES

State	Annual production of fuelwood* (million M^3)	Annual requirement of fuelwood* (millioon M^3)	Deficit* (million M^3)	Average per capita consumption of firewood† (kg /yr)	Average per capita consumption of crop waste† (kg./yr)	Average per capita consumption of dung cake† (kg./yr)
Haryana	0.11	3.4	3.29	10.5	78.3	255.7
Punjab	0.04	4.4	4.36	23.2	115.1	210.7
Rajasthan	0.23	1.0	0.77	49.2	15.0	140.8
Uttar Pradesh	2.09	28.9	26.81	20.8	62.7	211.0
Gujarat	0.18	8.0	7.82	32.4	8.5	91.6
Madhya Pradesh	1.41	14.1	12.69	61.8	45.6	189.5
Maharashtra	1.40	16.6	15.20	71.2	14.5	89.5
Bihar	0.36	18.7	18.34	11.5	79.8	265.4
Orissa	0.61	7.4	6.79	25.2	28.0	122.0
West Bengal	0.53	15.3	14.77	18.3	156.8	98.3
Andhra Pradesh	0.97	14.1	13.13	48.7	36.1	46.6
Karnataka	1.71	9.8	8.09	46.8	52.2	8.7
Kerala	0.55	7.1	6.55	31.4	83.2	0.2
Tamil Nadu	0.29	13.0	12.71	51.9	40.7	40.8

* *Source: Urja* (Energy) *Update,* May 1987 (New Delhi).
† *Source:* NCAER (1981).

It is a widely recognised fact that wood has become a scarce commodity in the last few years due to a variety of reasons like large scale deforestation and increased demand for cooking energy. As a result, the retail prices of wood have increased steeply in the last few years (CMIE, 1988). The tendency of retail prices at a few centres is shown in Table IV. Judging from the present retail prices of firewood and from conclusion (3) above, it is apparent that operating the gasifier system with *purchased* wood is clearly not a viable proposition. It might be argued that these prices do not reflect the actual cost of wood and include other costs like those for transport, etc. The cost of firewood (*Prosopis*) grown on wastelands has been estimated to be Re. 0.40 per kg. (Chaturvedi, 1985). The cost of cutting wood into small pieces is about 0.05 Re./kg. by electric saw and 0.5 Re./kg. if manual labour is employed, assuming that 20 kg. wood can be processed per man-day and that the labour rates are 10 Rs./man-day. The lowest cost of wood chips would thus be about 0.45 Re./kg. At this cost of wood chips, as can be seen from Tables I and II, the gasifier system is not viable economically for most of the combinations and would at best be marginally viable under the best circumstances of low capital cost, low discount rate and high diesel price.

There is some debate among biomass specialists regarding the yield and hence the cost of production of firewood from social and agro-forestry. Under favourable conditions, it is perhaps possible to obtain wood chips at a price less than 0.45 Re./kg. But in view of the scarcity of fuelwood, it is doubtful whether wood would be made available for gasification purposes rather than for selling in the market at higher returns. Several indices which show the scarcity/availability of firewood are listed in Table V for each State. The States of Haryana, Punjab, Rajasthan, Uttar Pradesh and Bihar, which were considered earlier from the point of view of operating hours, are marked by low per capita consumption of firewood, and (logically as a result) high per capita consumption of crop residues and dung cakes. Hence, it might be expected that large scale programmes of plantation on wasteland would not necessarily pave the way for large scale promotion of wood gasifier units for irrigation pumping.

CONCLUSIONS

Small scale gasifier systems coupled to diesel pumps for irrigation do not seem to be economically viable, compared to diesel-alone systems. The main parameters affecting economic viability are (*i*) capital cost of gasifier equipment, (*ii*) discount rate, (*iii*) cost of diesel, (*iv*) number of hours of operation and (*v*) cost of wood, including cutting costs. Even under favourable conditions of lower capital cost, lower discount rate and higher diesel prices, the cost of wood and the number of operating hours obtaining in various States do not permit viability in the near future. Hence, it might be desirable to concentrate R & D efforts in gasification on utilising essentially waste material. Also, as the operating hours per year are generally low for irrigation pumping, it seems desirable to limit the use of gasifier systems for other applications like power generation, process heat, etc.

V.V.N. Kishore*

REFERENCES

Centre for Monitoring Indian Economy (CMIE) (1988) Current Energy Scene in India, Bombay, May.

Chaturvedi, A.N. (1985). "Firewood Farming on Degraded Lands", *U.P. Forest Bulletin*, No 50, Dehradun.

Damour, Vincent et Marie-Sabine (1983). "Development of Small Scale Gasifiers for Irrigation Purposes in India", Jyoti Solar Energy Research Institute, Vallabh Vidyanagar.

Durgaprasad, M B., R N Pandya, S R Patel, V K. Jain and K.S. Shah (1985) "Field Implementation of Gasifier Systems for Irrigation", Paper presented at the Third USAID/Government of India Workshop on Alternative Energy Resources, New Delhi.

Government of India (1983) Public Electricity Supply, All India Statistics, General Review, 1982-83, Central Electricity Authority, New Delhi.

Indian Institute of Petroleum (1978). Assessment of Diesel for Agricultural Sector, Vol I, Dehrahun.

National Council of Applied Economic Research (NCAER) (1981). Domestic Fuel Survey with special reference to Kerosene (1978-79), New Delhi

Ramesh, S. and Kapil Thukral (1988). "Alternative Sources of Energy for Lift Irrigation in Indian Agriculture-A Case Study for Uttar Pradesh", *RERIC International Energy Journal*, Vol.10, No.1, June.

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* Fellow, Tata Energy Research Institute, New Delhi.

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EVALUATION OF VARIOUS FUELS FOR GASIFICATION

S.Kohli, P. Raman, V.V.N. Kishore
Tata Energy Research Institute
7, Jor Bagh, New Delhi-110 003.

ABSTRACT

Some properties relevant to gasification are measured certain fuels. A methodology for evaluation of these fuels for gasification on the basis of these properties is presented.

KEY WORDS

Biomass Fuels. Gasification.

INTRODUCTION

Successful gasification of any biomass depends largely on its physical and chemical properties. Considering the availability of a wide variety of biomass with varying properties, it is desirable to grade a fuel according to its suitability for gasification.

Some of the most important properties of the fuel in relation to gasification are: (i) calorific value (ii) moisture content (iii) ash content (iv) ash melting point. The other important parameters are particles size, bulk density, void fraction and fixed carbon content.

Though these properties are available in literature for different varieties of biomass, their values have been found to vary within a broad range. Regional variability in the quality of biomass and local climate cause a significant variation in these properties. Thus for the purpose of evaluation of these fuels for gasification, these properties were measured in the laboratory for some locally available fuels. In this paper, the results are presented and the data analyzed to identify fuels suitable for gasification.

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MEASUREMENT OF PROPERTIES

i) Calorific Value

An oxygen bomb calorimeter was used for calorific value determination. Each sample was broken into small pieces and oven dried at 110°C to make it moisture free. It was then powdered and pelletized, weighed and placed in a container filled with oxygen to a pressure of about 20 atm and electrically fired. If the sample could not be pelletized, it was taken in a gelatine capsule and then placed in the bomb for firing. The heat released due to combustion was determined by measuring the rise in temperature of water around the sample container with a Beckmann thermometer. The water equivalent of the bomb calorimeter system was determined by carrying out the test with a sample of benzoic acid.

To account for the heat exchange between the calorimeter parts and the surroundings, the Dickinson correction (1) was applied to the observed temperature rise.

The calorific value of the sample was thus calculated as

$$H = \frac{W.T - E}{M}$$

Where W = water equivalent of the system in kcal/°C
T = corrected temperature rise in °C
E = energy equivalent of the nichrome wire and cotton fuse used to ignite the sample in kcal.
M = mass of the sample in kg.

The calorific value so determined is the higher calorific value of the sample in kcal/kg on dry basis.

Error estimation

The error in the calorific value determination by the above method was estimated using the root-mean square error formula (2). With the sensitivity of ±0.01 °C for Beckmann thermometer and ± 0.1 mg for the weighing balance, the typical error in the calorific value measurements is of the order of ± 1%.

The temperature measurement is the limiting factor and accounts for over 99.9% of the error.

For each kind of biomass, measurements were carried out for three samples. The averages of these values are listed in Table 1. The percentage deviation is given in parenthesis.

(ii) Moisture Content

To determine the moisture content of a fuel, a known weight of the sample was oven dried at 110°C for 3-4 days till its weight stabilized. The difference in the weight of wet and dry samples gives the moisture content of the fuel.

The values in Table 1 are averages of measurements on three samples of the fuel. Percentage deviation is given in the parenthesis.

(iii) Ash Content

A known weight of the oven dried sample was heated to about 700 °C in a furnace. At this temperature all the carbon and volatile matter in the sample get oxidized and only ash is left behind.

Table 1 shows the percentage ash content of the different fuels on dry basis. The values given are mean of two measurements.

(iv) Ash Melting Point

The ash obtained by heating the sample to 700°C was further heated in steps of 100°C. After each step, the sample was cooled down to find out if it had melted. By this method, only a range of temperatures was obtained within which the ash of the sample melts.

EVALUATION OF FUELS

The gradation of fuels was based on the following properties measured as described above.

1. Calorific value (C.V.)
2. Ash content (A.C.)
3. Moisture content (M.C.)
4. Ash melting point (A.M.P.)

Weights were assigned to each of these properties by mutual comparison as shown below.

C.V.	C.V. -2	C.V.-3	C.V. -2	7
	A.C.	A.C.-3	A.C. -2	5
		M.C.	M.C. -2	2
			A.M.P.	1

Here each property was compared with the other property from th point of view of gasification and the more important of the tw was written in the cell. Score of 2 or 3 was given depending on whether the difference in importance of the two properties is small or large. Basic score of 1 was given to the property which did not earn any score in the above process.

CALCULATION OF WEIGHTS

The scores for each of these properties are calculated by adding their scores in different cells.

Scores for calorific value = 7
Ash content = 5
Moisture content = 2
Ash melting point = 1

Total = 15

The weight can be obtained by dividing the individual score by the total score.

Weight for calorific value W1 = 7/15 = 0.467
Ash content W2 = 5/15 = 0.333
Moisture content W3 = 2/15 = 0.133
Ash melting point W4 = 1/15 = 0.067

Conversion of property values into points

For gradation of fuels, the values of each property are converted into points as shown below.

1. Calorific value : A range of 0-10 points is defined for calorific values of 3000-5000 kcal/kg.

Calorific value	Score
3000 kcal/kg	0
5000 kcal/kg	10

The points for any calorific value within this range can be calculated by linear interpolation.

2. Ash content: Here the points have been assigned as below.

Percentage ash content	Score
60	0
0	10

3. Moisture content:

Percentage Moisture content	Score
20	0
0	10

4. Ash melting point:

Melting point	Score
<900 °C	0
900-1000 °C	5
>1000° C	10

TABLE 1 PROPERTIES OF DIFFERENT FUELS

Fuel	Calorific value kcal/kg (% deviation)	Ash content % by Wt. (% deviation)	Moisture content % by Wt.	Ash melting point deg C
1. Pure Cattle dung	3595 (0.5)	20.2 (0.7)	8.0	900-1000
2. Cattle dung cake	3022 (0.5)	38.4 (7.8)	7.6	900-1000
3. Cattledung+ Sawdust(1:2 dry wt.basis)	3610 (0.6)	25.0 (11.3)	8.3	900-1000
4. Groundnut shell	4334 (1.2)	15.2 (2.6)	10.9	> 1000
5. Wheat straw	4148 (2.1)	8.1 (10.0)	8.9	900-1000
6. Mustard Stalk	4507 (0.7)	2.9 (6.9)	11.3	> 1000
7. Sawdust	4720 (3.8)	10.0 (7.2)	8.0	1000
8. Wheat Boor	4280 (0.9)	4.4 (2.1)	9.7	< 900
9. Rice Husk	3474 (1.2)	17.2 (1.9)	9.6	> 1100
10. Coal Powder	3388 (2.8)	50.1 (2.4)	5.4	>1000
11. Pearl Millet (Bajra) Cob	4234 (2.1)	4.7 (4.0)	7.3	< 900
12. Sorghum Stalk	4040 (2.4)	3.5 (11.6)	9.5	900-1000
13. Cattle Dung+ Coal Powder (1:9 on dry wt. basis)	3676 (1.6)	47.8 (2.9)	2.9	>1000

Calculation of final scores

If S1, S2, S3 and S4 are the scores of a particular fuel for calorific value, ash content, moisture content and ash melting point respectively and W1, W2, W3 and W4 are respective weights for these properties, then the final score for a fuel can be determined by:

$$S = S1\ W1 + S2\ W2 + S3\ W3 + S4\ W4$$

Table 2 lists out the scores for the fuels considered in the study.

TABLE 2 CALCULATION OF FINAL SCORE

Fuel	Calorific value kcal/kg (W1= S1	Ash content (W2= 0.333) S2	Moisture content (W3= 0.1333) S3	Ash melting (W4= 0.067) S4	Score S=S1 W1+ S2W2+ S3W3+ S4W4
1. Pure cattledung	2.98	6.63	6.0	5	4.73
2. Cattledung cake	0.11	3.6	6.2	5	2.41
3. Cattledung+ Sawdust	3.05	5.83	5.85	5	4.48
4. Groundnut shell	6.67	7.47	4.55	10	6.87
5. Wheat straw	5.74	8.65	5.55	5	6.63
6. Mustard Stalk	7.54	9.52	4.35	10	7.94
7. Sawdust	8.6	8.33	6.0	5	7.92
8. Wheat Boor	6.4	9.27	5.15	0	6.76
9. Rice Husk Briquettes	2.37	7.13	5.2	10	4.84
10. Coal Powder	1.94	1.65	7.3	10	3.10
11. Pearl Millet (Bajra) Cob	6.17	9.22	6.35	0	6.80
12. Sorghum Stalk	5.2	9.42	5.25	5	6.93
13. Coal Powder + Cattledung	3.38	2.03	8.55	10	4.06

CONCLUSIONS

As seen in Table 2, Mustard Stalk has the highest score among the fuels considered, closely followed by sawdust. Sorghum stalk and groundnut shell are next in the list. It should be emphasized that this evaluation parameters such as the fixed carbon content, particle size, void fraction and bulk density which play a significant role in gasification process have not been considered in this study. Incorporating these in the evaluation of fuels might change the gradation of these fuels.

Assigning of weights to different parameters was somewhat subjective in this study. For a more comprehensive evaluation, these weights should be assigned based on data which can quantify the effects of these properties on gasification.

ACKNOWLEDGEMENT

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REFERENCES

1. Dickinson H.C. (1915); *Bulletin of the National Bureau of Standards (US).*

2. Doeblin E.O. (1966); *Measurement Systems :Applications and Design, McGraw Hill Book Company.*

Paper Received Late

A Review of Design Procedure for Downdraft Gasifiers

V.V.N. Kishore and V.L.N. Murthy
Tata Energy Research Institute, New Delhi

ABSTRACT

The design of gasifiers hitherto is largely empirical. The principal design parameters are-specific gasification rate, gas residence time and area of air nozzles. The derived parameters are-diameter of hearth for throated design, total length of combustion - reduction zone, air velocity through nozzles etc. In the present paper, a survey of existing designs for small sized gasifiers has been carried out and the variation in the above mentioned parameters has been compiled.

INTRODUCTION

Development of wood gasifiers for irrigation pumping and power generation has been an important activity in India since 1980. Several institutions are actively involved in developing new designs of biomass gasifiers testing and demonstrating them in the field. There are currently two manufacturing firms. The Department of Non-Conventional Energy Sources (DNES) is also actively encouraging demonstration of gasifier units and currently about 100 gasifier systems are installed in various parts of the country for demonstration purposes.

The design rules followed for fabrication of gasifier equipment are largely empirical at present and are based on the experience gained during second world war. However, if biomass gasification as a renewable energy technology has to gain respectability and reliability of operation especially with biomass other than wood and charcoal, the design rules would have to be more rigorous and have to be based on a detailed analysis of the physical and chemical processes occurring in various zones of a gasifier. It is also widely known that the various processes occurring in a gasifier are very complex and not easily amenable for analysis and formulation. As a first step in this direction this paper attempts to examine the different designs available at present in the country and draw certain conclusions regarding the design rules for different parameters.

PARAMETERS REQUIRED IN THE DESIGN OF GASIFIERS

ER is defined as the ratio of oxygen supplied per kg wood to the stoichiometric requirement. ER fixes the amount of air supplied for gasification. A value of 0.3 for ER is the theoretical optimum

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as ER approaches 1.0, combustion reaction is predominant and as it tends to zero, pyrolysis is the major process. All the gasifier designs were based on the above mentioned optimum. For a given (or desired) biomass consumption rate, the volumetric rate of air can be directly calculated from ER.

Specific Gasification Rate (SGR)

SGR is the volumetric flow rate of gas per unit area based on throat diameter, the gas volume being measured at standard conditions. The recommended SGR falls in the range 0.3-1.0 ($Nm^3\ h^{-1}\ cm^{-2}$) (1). Within the framework of the existing empirical design charts, it is a primary parameter, since other parameters like total nozzle area, height of nozzles from throat, and diameter at air inlet are fixed, once a value is assigned to SGR. Higher SGR implies lower throat area which impairs fuel bed movement.

Specific Solid Flow Rate (SSR)

SSR is the mass flow ($kg\ h^{-1}\ cm^{-2}$) of fuel measured at throat. It is a derived parameter since it can be obtained from SGR. As one kg of wood approximately gives 2.4 Nm^3 of gas, SSR can be related to SGR as given below.

$$SSR = SGR/2.4 \qquad (1)$$

Gas Residence Time τ

It is defined as the average time spent by the gas phase in the reaction zone (sec). If V is the total volume of the reactor (from air entrance to grate), ϵ is the void fraction (volume of voids in the bed/total volume of reactor) and G is the gas flow rate ($Nm^3\ h^{-1}$), gas residence time is given by

$$\tau = \frac{V \epsilon}{G} \times \frac{273}{T} \times 3600 \text{ Sec} \qquad (2)$$

where T is the average temperature (K) inside the reactor. Much attention has not been paid to this parameter which controls the conversion in chemical reactions. The above equation assumes plug flow conditions and for a realistic calculation of τ the residence time distribution should be taken into account. From theoretical considerations Gumz (7) had recommended a value of 0.5 seconds.

Air Blast Velocity V_b (ms^{-1})

This is the linear velocity of air in the nozzle under standard conditions. The range of V_b proposed is 15-30 ms^{-1}. It is argued that higher air blast velocities help in higher penetration of air into the bed and also prevent formation of hot spots.

Total Nozzle Area A_m (cm^2)

This can be obtained from the existing empirical correlation between (A_m/A_h) and SGR, and A_h is the throat area. Alternatively, it can be obtained if a value is fixed for air blast velocity V_b, as follows.

$$A_m = G_a/V_b \tag{3}$$

where G_a is the volumetric flow rate of air. For small sized gasifiers the values of A_m obtained by the two methods are found to be quite different.

Nozzle Diameter (d) and Number (N)

They are related to total nozzle area A_m as follows.

$$\frac{\pi}{4} d^2 N = A_m \tag{4}$$

It can be seen that fixing d would automatically fix N or vice versa. A decision on the number of nozzles seems to be completely arbitrary.

Others

The distance from throat to nozzles, the diameter at air entrance etc. can be obtained from the existing empirical curves. The distance from throat to grate also seems to be decided arbitrarily. The total height and volume of the hopper is usually decided from considerations of time of operation needed and the bulk density of the fuel.

Various other factors like insulation, air pre-heating, central versus side tuyeres etc. has so far been left to the imagination of the designer and there are no real arguments for one or the other.

A SURVEY OF THE EXISTING DESIGNS

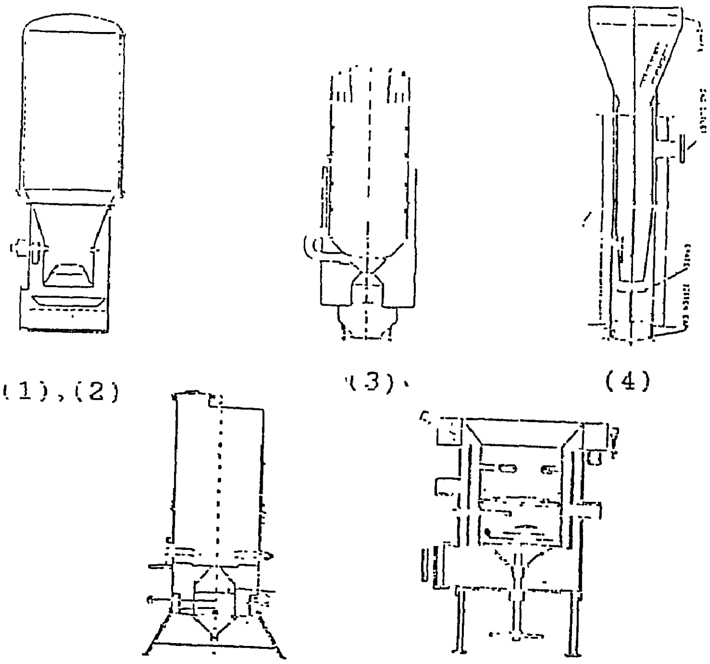
The reference volume of Kaupp [1] and the design rules outlined by Graf [2] are available for us for comparison. Small, wood gasifier systems with a production rate of about 10 Nm^3 h^{-1} had been developed by Jyoti Solar Energy Research Institute [3] and IISc., Bangalore [4]. A similar gasifier designed for operation with charred corn-cobs had been developed by IIT, Delhi [5]. The results of experiments conducted by Jenkins (6) on downdraft gasifier are also available. The IISc., Bangalore has a throatless design and the other gasifiers are conventional throated designs. From the actual geometries employed in these designs, various parameters listed in the previous section have been calculated and compared to those obtained using reference (1) and (2).

A summary of the above calculations is provided in Table 1. The various designs are schematically represented in Fig. 1

Table 1 : Comparison of Parameters

Reference No·	1	2	3	4	5	6
PARAMETER						
SGR $Nm^3\ h^{-1}\ cm^{-2}$	0.3-1.0	0.3	0.3-0.5	.09-0.2	8-.95	0.1-0.3
SSR $kg\ h^{-1}\ cm^{-2}$	0.35-0.5	0.12	0.13-0.21	0 04-0.083	0.34-0.40	0.05-0.4
Throat Diameter D_t (mm)	36-65	67	35-55	80[c]	50-55	150
Nozzle diameter d (mm)	2.5-5	1.8	2.6-4.5	19	2.5-5	13
Air blast[a] velocity V_b (m/s)	16.5-4.2	34	16.5-5.2	3.3-50	18.5-4.2	9-14
Residence[b] time τ (sec)	0.25	0.1	0.05-0.08	0.5-0.9	0.14	0.1-0.6

[a] Air volume at standard conditions.
[b] Gas volume meausred at 700°C.
[c] Throatless design with tapered firebox.



(1),(2) (3) (4)

(5) (6)

1,2,3,4,5,6-Reference numbers

FIG.1

Some general conclusions can be drawn from the above table as listed below.

1. The specific gasification rates obtainable in throatless designs seem to be much less compared to throated designs. A lower SGR is a desirable feature as it fecilitates better fuel flow, but it also calls for providing additional insulation. Infact our own experiments and calculations show that lower SGRs are invariably linked with better insulation of the reactor.

2. There seems to be a wide variation in air blast velocity. the low velocities obtainable in IISc design indicate that good air distribution does not necessarily require high air velocities.

3. The residence times of almost all the designs are much less than the recommended value of 0.5 sec. It seems that a value of about 0.1 sec would be sufficient for satisfactory operation.

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REFERENCES

1. Kaupp, A. and Gross, J.R., Small Scale Gas Producer - Engine Systems, GATE, 1984.

2. Graf, U., Design Rules for Downdraft Gasifiers, GATE, 1983.

3. Damour, V. and Damour, M., Development of Small Scale Gasifiers for Irrigation Purpose in India, 1983.

4. Dasappa,s.,et al, An efficient Gasifier Geometry for All power Levels,ASTRA.

5. Gaur, S., Anuradha, N., Rao, T.R., Iyer, P.V.R. and Grover, P.D., Development of a Biomass Gasification System for 5-hp Irrigation Pumps, paper presented at the Third Annual WorkShop On Biomass and Coal Conversion Programmes of the US Agency for International Development, Government of India Alternative Energy Resources Development Project, held in New Delhi, 1985.

6. Jenkins, B.M., Downdraft Gasification Characteristics of Major California Residue - Derived Fuels, PH.D Thesis, University of California, Davis, 1980.

7. Gumz, W., Gas Producers and Blast Furnaces, Theory and Metnods of Calculation, Jhon Wiley and Sons Inc., New York, 1950.

Paper Received Late

Design and Test Performance of a Throatless Downdraft Gasifier with a Low Specific Gasification Rate

P. Raman, S.D. Sharma, S. Kohli and V.V.N. Kishore

Tata Energy Research Institute, New Delhi

ABSTRACT

A throatless downdraft biomass gasifier equipped with grate shaking and fuel agitation facility has been designed, fabricated and tested. The design details of gasifier, tar and dust removing units along with the data collected on tar and dust content and chemical composition of the gas using wood chips as fuel are presented.

INTRODUCTION

Downdraft gasifiers with throatless design had been developed earlier by Reed (1) and Dasappa et al, (2). The present design attempts to achieve very low specific gasification rates of the order of 0.03 $Nm^3/hr. cm^2$ and to solve the problem of clinker formation and bridging. The combustion reduction zones had been insulated to produce good quality gas by maintaining a high firebox temperature. The present design has evolved as a result of continuous trials and modifications. This paper gives the fabrication details of the gasifier, dry-cooler, filter and the results obtained by analysing the gas for tar, dust and chemical composition, using wood as fuel.

DESCRIPTION OF THE SYSTEM

A schematic diagram of the gasifier unit coupled with an irrigation pump is shown in fig. 1. The fabrication details of various components are given below.

The Firebox

A throatless design (fig.2.) for the gasifier has been chosen to facilitate fuel movement in the firebox and to allow the usage of even large wood chips. The firebox with 20 cm internal diameter was fabricated from 3 mm thick stainless steel (SS310) sheet. Two stainless steel nozzles each with 10 mm opening protruding into the firebox through the wall were diagonally opposite to ensure proper distribution of air across the bed. A third stainless steel nozzle provided with a valve for adjusting air flow rate was centrally located 5 cm above the box to render proper distribution of extra air to be supplied for gasification. The distance between side nozzles and grate has been decided on the basis of results of several runs aimed to

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optimize the gas quality. The firebox was insulated with a 5 inch thick annulus of glass wool. The product gas was drawn through the annulus around the insulation whereby larger dust particles can be removed by gravity separation(3).

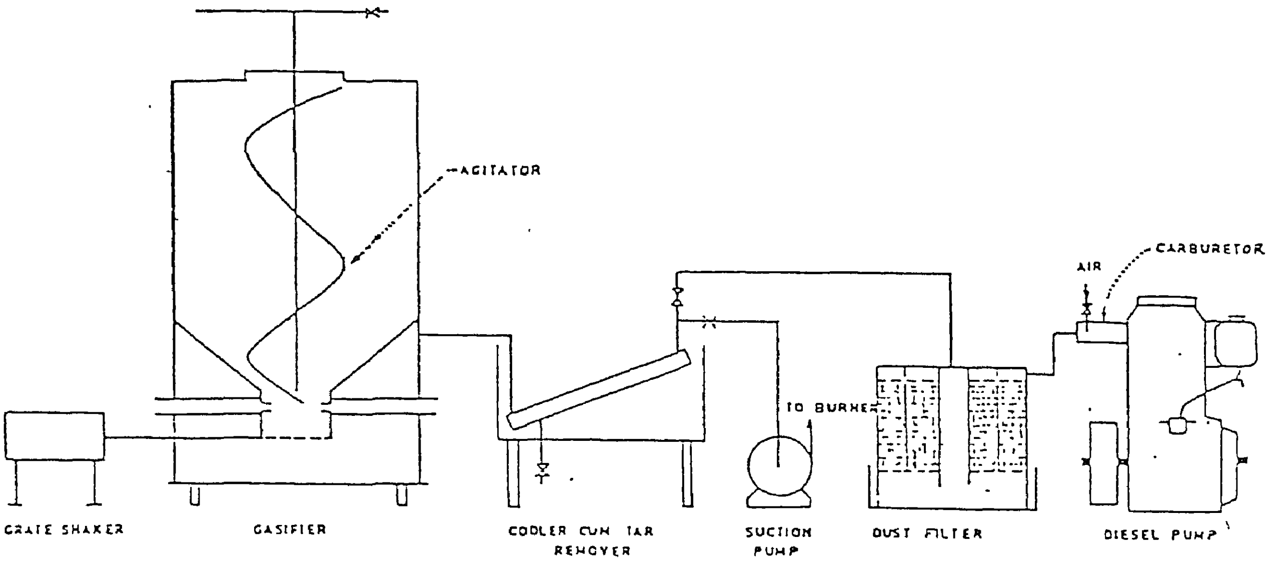

Fig. 1. The schematic diagram

Grate Shaking Arrangement

A grate shaking mechanism (fig. 2) has been developed for continuous removal of ash and hence for prevention of clinker formation. The Grate, consisting of 10 mm mild steel parallel rods with 10 mm spacing, is attached to an arm taken out of the gasifier unit through a bellow coupling. This is connected to a reciprocating unit to impart vibrations to the grate.

Agitator

A helical type of agitator has been finally found to be the most suitable among the various designs tested in order to control the bridging of fuel in hopper. The shaft of the 20 cm. dia agitator is hollow and is connected to the central air nozzle. This shaft is taken out of the gasifier from the top lid through a sealed ball bearing. Two horizontal arms connected at right angles with the central shaft facilitate shaking of the entire bed.

Gas Cooler Cum Tar and Dust Remover

Raw product gas coming out from the gasifier is fed to a dry cooler based on evaporative cooling. The dry cooler (Fig. 3) made of mild steel sheet, is a rectangular box immersed in a water bath.

The gas was allowed to pass upward between watercooled parallel walls of the rectangular box where most of the tar condenses. This gas is either burnt (fig.1) or fed in to a dust filter. The dust filter (fig. 5) consisted of four interconnected concentric chambers each provided with a bed of nylon fibers and on oil bath. The gas is allowed to pass alternately over the oil surface and nylon filter where most of the remaining fine dust particles and tar were removed. Clean gas is finally fed into a dual fuel engine through a carburetor.

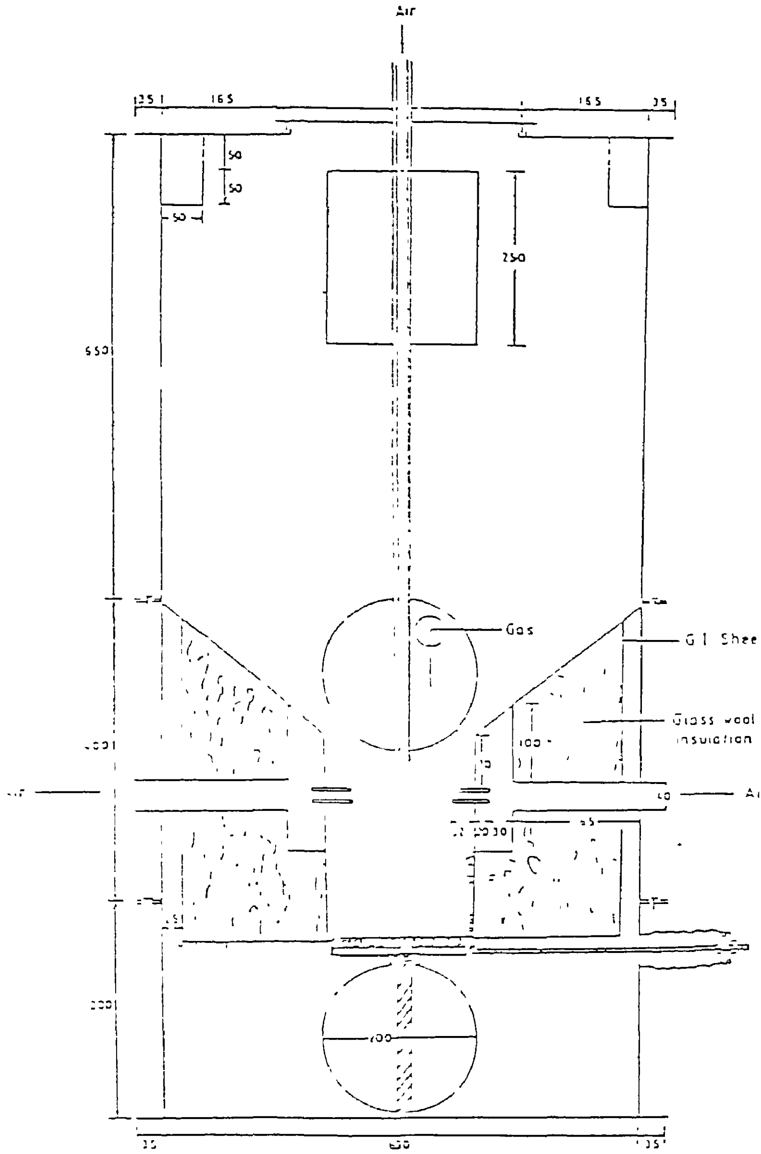

Fig. 2. Design of the gasifier

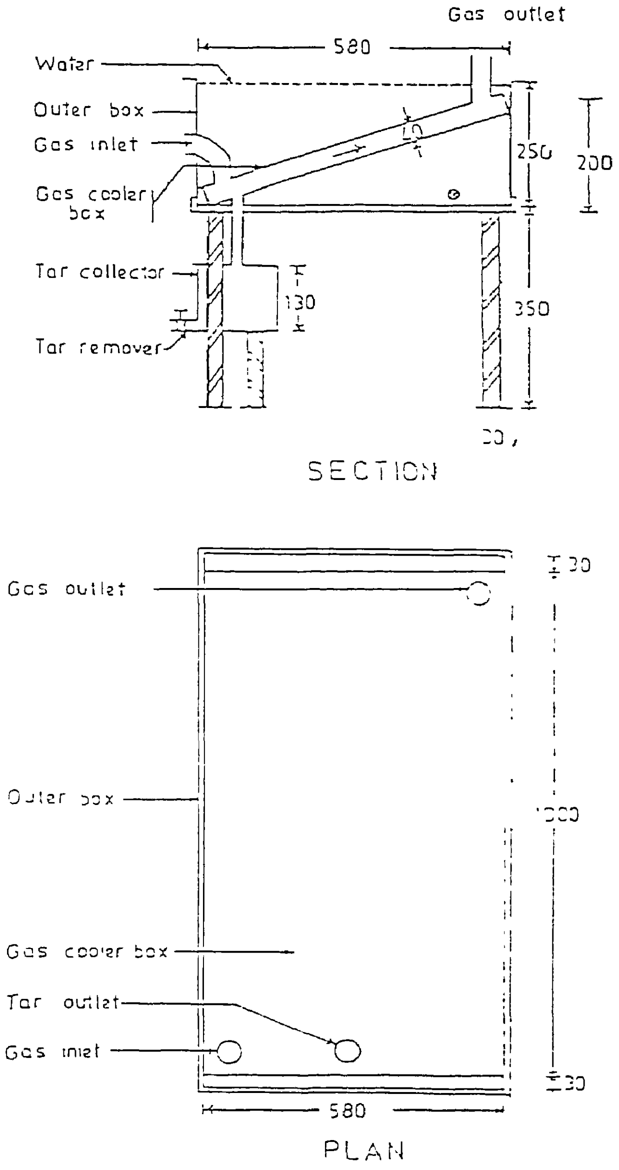

Fig. 3. Cooler cum tar remover

PERFORMANCE OF THE GASIFIER

The problems due to fuel bridging and ash clinkering in the gasifier could be completely eliminated by continuous grate shaking and intermittent fuel agitation during the operation of the gasifier. It was found that continuing grate shaking for 20-30 minutes after shut down prevented clinker formation, especially while using fuels with high ash contents.

The specific gasification rate was calculated to be 0.03 Nm^3 Cm^{-2} hr^{-1} against reported values of 0.1 Nm^3 Cm^{-2} hr^{-1} for throatless and 0.30 - 1.00 Nm^3 Cm^{-2} hr^{-1} for throated downdraft gasifiers. Observed tar content in the raw gas (output rate 10 Nm^3 hr^{-1}) was comparatively less than that reported for nearly same gasification rates (Fig. 4). The low tar contents are attributed to the large firebox temperature (~1500°C) attained with insulation.

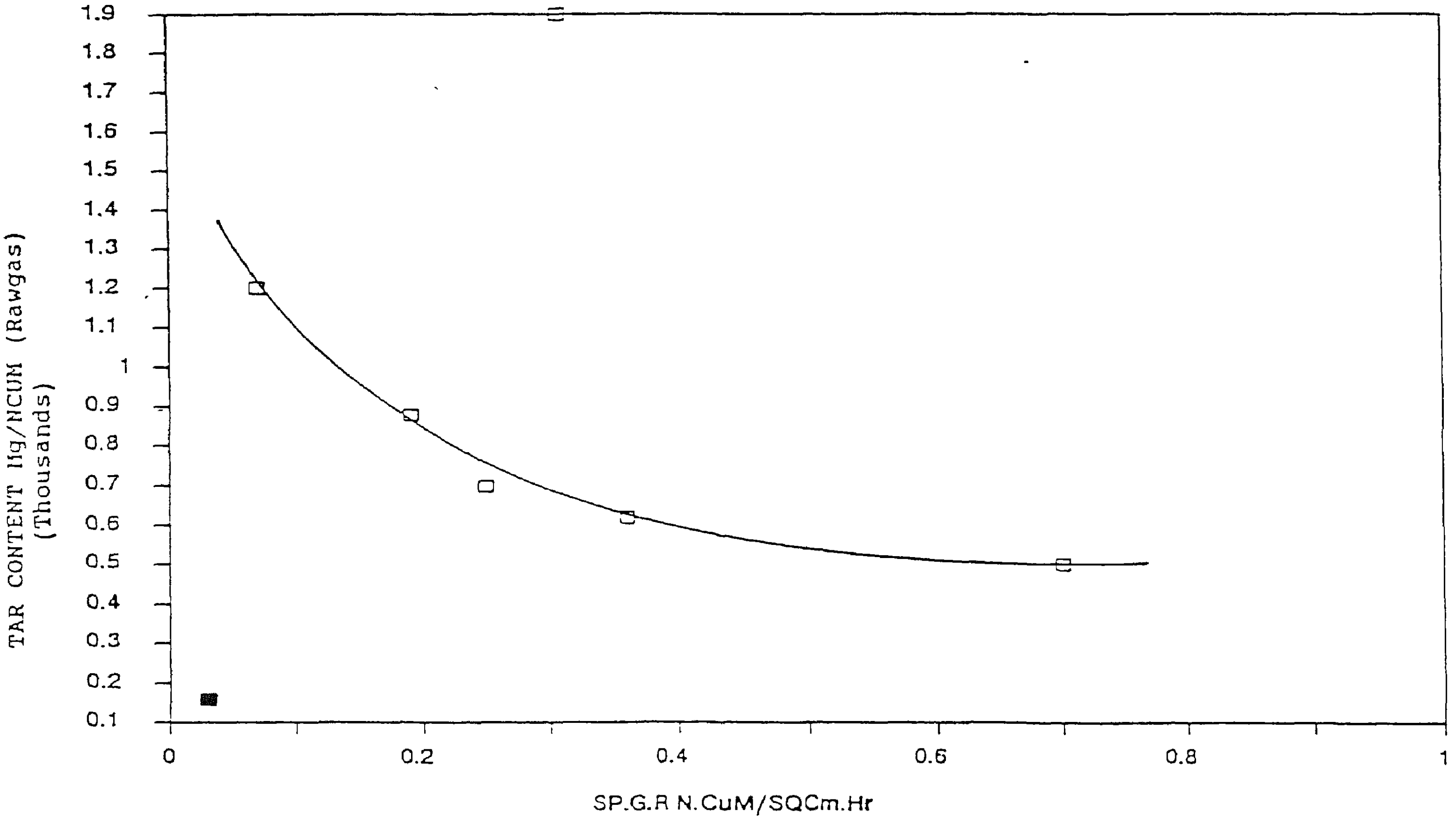

Fig. 4. Variation of tar content with specific gasification rate (from literature)

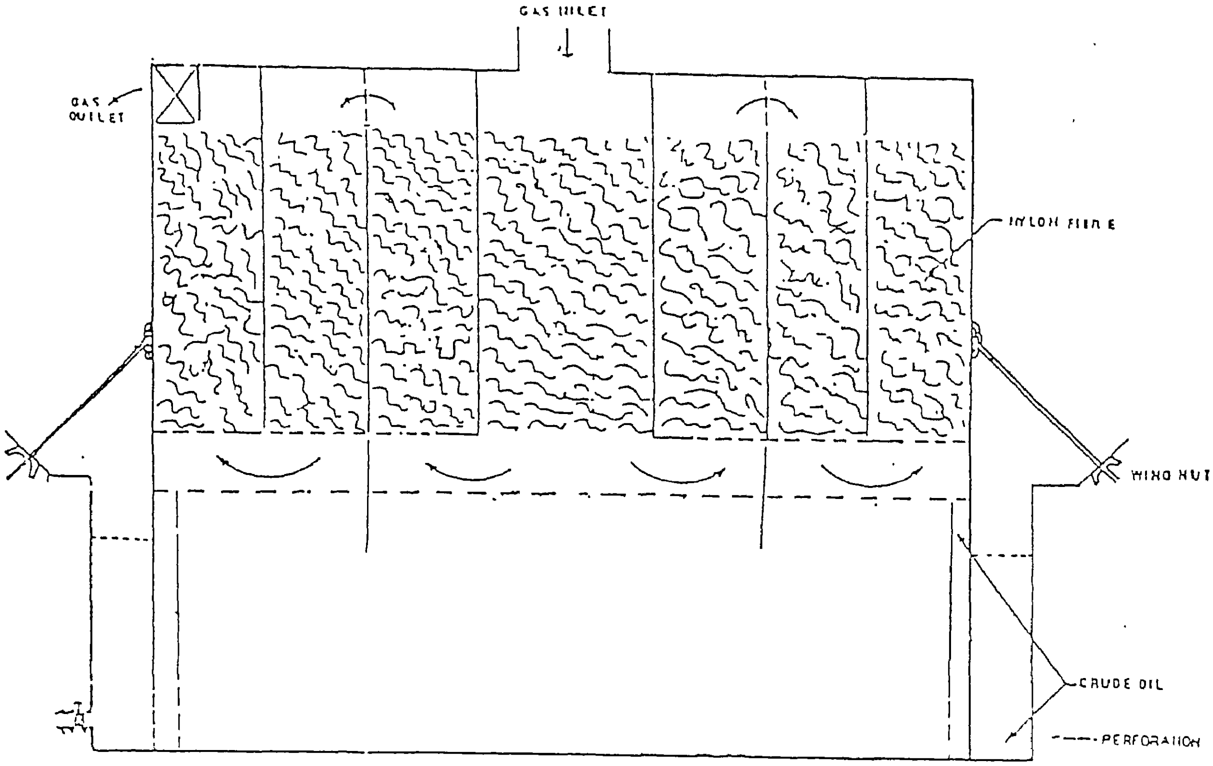

Fig. 5. Dust filter

Table 1: Tar, dust and moisture contents.
Fuel: wood chips size 4 x 12 cm

Sample position	Tar mg/m^3	Dust mg/m^3	Moisture g/m^3
Raw gas (No. of Expts:6)	89.6-145.2	22.0-138.3	19.0-20.0
After cooler (No. of Expts:7)	7.0-37.0	6.0-25.0	1.0-7.6

Table 2: Chemical composition of product gas
fuel: wood chips

Size	% Composition					
d X l (cm)	Co	H_2	CO_2	O_2	C_nH_m	N_2
4 x 4 (No. of Expts:9)	14.09	12.31	13.10	1.21	0.17	59.38
4 X12 (No. of Expts:7)	13.23	12.76	13.05	0.43	0.26	60.25

d = diameter, l = length,
standard deviation = 1.75 (maximum).

The efficiency of cooler cum tar remover was examined by comparing the tar, dust and moisture content of gas samples collected from the outlets of different units (table 1). Temperature of the gas at inlet and outlet of the cooler were 100-120°C and 32-34°C respectively. The maximum pressure drops measured across the cooler and filter were 4 mm and 10 mm of water respectively.

Experiments with different sizes of wood chips have clearly demonstrated the adaptability of the gasifier even for larger size of chips. Change in chemical composition of the gas with fuel size was found to be negligible (table. 2). Diesel replacements of 60-65% have been achieved with the operation of the 5 HP diesel pump for the maximum period of abut 115 hours.

ACKNOWLEDGEMENT

The work reported in this paper has been carried out under a project entitled "Design fabrication, testing and field demonstration of biomass gasifier systems for irrigation pumping pumping", sponsored by the Department of Non-Conventional Energy Sources.

REFERENCES

1. Reed, T.B., Levic, B., and Das, A., Biomass gasification for power fuels and chemicals, 5th Canadian Bioenergy R & D Seminar, Ottawa 1984, pp 48-55.

2. Dasappa, S., Mukunda, H.S., Baliga, B.N., Shrinivasa, V. and Suresh, H., An Efficient Gasifier Geometry for All Power Levels. Report from Indian Institute of Science, Bangalore.

3. Perry, R.H. and Chilton, C.H., Chemical Engineer's Hand Book. Fifth Edition.

Proceedings of "The 1st National Meet on Recent
Advances in Biomass Gasification Technology"
at I.I.T. Bombay, Sept. 11-12, 1989, pp. 158-162.

MODELLING OF PYROLYSIS ZONE IN A DOWN DRAFT BIOMASS GASIFIER

V.L.N. Murthy and V.V.N. Kishore
Tata Energy Research Institute
232 - Jor bagh, New Delhi

Abstract

The pyrolysis zone of a continuous moving bed down draft gasifier is studied with a heterogeneous steady state model for heat transport, which incorporates effective thermal conductivity of bed of particles, coupled with first order pyrolysis kinetics. The resulting set of equations are solved for obtaining the temperature profile in the pyrolysis zone. The effect of various parameters on temperature profile is studied. Predictions of the model are compared with experimental data available in the literature.

Introduction

Biomass gasification involves complex physico-chemical processes which can be broadly classified into pyrolysis, drying, combustion, and reduction. The relative position of the regions where these processes occur depend on the temperature profile in the reaction space. In a counter current (up draft) gasifier the pyrolysis zone is followed by reduction and combustion zones. In a cocurrent (down draft) gasifier pyrolysis zone is followed by combustion and reduction zones, in that order.

The amount of volatile matter in the product gas from a gasifier depends on the degree of completion of cracking reactions. Hence proper sizing of combustion zone, which provides enough residence time for cracking, is essential for minimal tar content in product gas. The residence time of gases greatly depends on the extent and rate of devolatilization. As these are dependent on the temperature profile in the pyrolysis zone, an understanding of the behaviour of pyrolysis zone would be very useful. In the present article a simple model is presented for the analysis of the pyrolysis zone.

Most of the literature available in the area of moving bed biomass gasification [1,2,3] is confined to various reactions and transport processes in the combustion and reduction zones and not much information is available specifically on moving bed pyrolysis. A number of articles deal with generalised models for gas-solid contactors. Amundson et.al [4,5] in their series of articles on gas-solid contactors presented analytical solutions for temperature and conversion profiles. Schaefer [6] studied the steady state behaviour of moving bed reactors employing an exclusively thermal model. Arce et.al [7] analysed the parametric sensitivity of counter current moving bed reactors.

Most of the models mentioned above incorporate convective heat transfer coefficients to characterise heat transfer in the bed, which do not really reflect the situation at least in high temperature regions where radiative transport is predominant. In the present work, the effect of radiative transport is accounted by using effective thermal conductivities.

Description of the Model

The main assumptions based on which the model is developed are: (a) Steady state operation. (b) Radial gradients are negligible. (c) Gas phase contribution by convection to energy transport is negligible. (d) Effect of temperature on physical properties is negligible. (e) Non uniformity of voidage near the column wall is negligible.

Pyrolysis Rate Expression

Groeneveld [8] proposed a first order Arrhenius type rate expression from the thermo gravimetric analysis of wood. The expression of Groenevel can be written as

$$\frac{dX}{dZ} = \frac{K}{u_p} (X_E - X) \qquad (1)$$

where

$$X = 1 - \frac{M_s}{M_{so}}, \quad X_e = 1 - \frac{M_{se}}{M_{so}}$$

K is the first order kinetic constant defined by the Arrhenius expression $K = K_o \exp(-E/RT)$ and u_p is the linear velocity of the solid phase. It is assumed that the solid phase shrinks as pyrolysis proceeds and the volumetric flow rate is defined by

$$V = V_o (1 - x) \qquad (2)$$

wheere V_o is the inlet volumetric flow rate of solid phase given by

$$V_o = \frac{M_{so}}{\rho_s}$$

Because of the shrinkage of solid phase, void fraction increases as axial dispersion of the solid phase is assumed to be negligible.

$$\epsilon = \epsilon_o (1 - x) + x \qquad (3)$$

The linear velocity of the solid phase, at any intermediate conversion is given by

$$u_p = \frac{V_o (1 - x)}{A (1 - \epsilon)} \qquad (4)$$

Thermal Energy Balance

The various components that contribute to energy transport are: **(a)** Sensible heat due to the bulk movement of solid phase, **(b)** Radiative and conductive transport, **(c)** Heat of reaction of pyrolysis process, **(d)** Latent heat involved in drying and **(e)** Loss to the ambient.

Energy balance over a differential element dz leads to the equation

$$- A \frac{d(K_e \, dT/dZ)}{dZ} + M_{so} (dX/dZ) \{ - H - C_{ps} (T-T_o) \} + M_{so} (1 - X) C_{ps} (dT/dZ) + \pi D h (T - T_a) = 0 \qquad (5)$$

In the above equation K_e represents the effective thermal conductivity of bed of wood particles, which takes into account various modes of heat transfer. Many correlations are available in the literature and their predictions vary widely. A recent study by Botterill et. al. [9] on effective thermal conductivities at high temperatures and the subsequent article [10] in which predictions of various correlations are compared with experimental results highlight the inability of most of these correlations to account for radiative heat transfer. However the correlations proposed by Bauer as referred by Melanson [11], though underestimated K_e at high temperatures, gave better predictions. In the present analysis Bauer's equations [11] are used. In the absence of information on the composition of pyrolysis gases, it is assumed that the properties of these gases are same as those of air. It is also assumed that the heat of reaction for pyrolysis is negligible. It is assumed that the moisture content of wood is zero for simplicity sake.

Boundary Conditions

Fresh feed enters the column at ambient temperature with negligible pyrolytic conversion. This leads to the first boundary condition.

$T = TA,\ X = 0$ at $Z = 0$ (6)

In a down draft gasifier combustion occurs immediately after pyrolysis and a temperature of about 1100°C is usually attained in the combustion zone. Hence the second boundary condition has been taken as

$T = 1100^{\circ}C$ at $Z = L$ (7)

where L is the height of pyrolysis zone.

Equations (1) and (5), along with boundary conditions (6) and (7) are solved using fourth order Runge-Kutta method. The strategy adopted is called `shooting method'. A value of dT/dZ at $Z = 0$ is initially guessed, and the entire temperature profile is obtained. The value of T at $Z = L$ is then compared with the boundary condition (eq. 7). The computation is repeated, by changing dT/dz at $Z = 0$, till the boundary condition (eq. 7) is satisfied.

Results and Discussions

(1) **Effect of Mass Velocity (Mso/A)** : With the increase the mass velocity, the high temperature zone (above 600 K) progressively shifts towards combustion zone as shown in fig. 2. As most of the biomass samples pyrolize in the temperature range 600 - 800 K, the point of highest mass loss rate also moves towards combustion zone. Pyrolysis virtually takes place in combustion zone for mass velocity above 150 kg/h m^2. The empirically recommended value of mass velocity [12] of 250 kg/h m^2 seems to be very high and might lead to an unsatisfactory operation of the gasifier.

(2) **Effect of Heat Loss Coefficient** : Increase in heat loss coefficient has a similar effect as the mass flow rate as shown in fig. 3. An insulation around the pyrolysis zone or any other strategy in which hot product gases transfer heat to pyrolysing bed would have a positive effect on the pyrolysis zone temperature.

(3) **Effect of Column Diameter** : Increase in column diameter, for a fixed mass velocity, in the absence of any heat loss to the ambient, has no impact on the temperature profile as is evident from equation (4). But in the presence of side losses, increase in D shifts the high temperature zone towards combustion zone.

(4) **Comparison of the Model Prediction** : Parikh et. al. [13,14] studied the performance of a down draft wood gasifier under varying operating conditions. They obtained experimental temperature profiles in the pyrolysis zone. The parameters when the gasifier is operating in the blower mode, in which case the mass velocity is higher compared to that in the engine mode, have been incorporated in the present model. The predictions of the model agree reasonably well with the experimental data as shown in Fig. 4.

REFERENCES

01. Jin-Shi Chen, Wesley W. Gunkel, Modeling and Simulation of Co-Current Moving Bed Gasification Reactors - Part 1. "A Non-Isothermal Particle Model'. Biomass 14, (1987) 51-72.

02. Jin-Shi Chen, Wesley W. Gunkel, Modeling and Simulation of Co-Current Moving Bed Gasification Reactors - Part II. A Detailed Particle Model, Biomass, 14, (1987) 75-98.

03. Bhattacharya, S.C., Basak, A.K., "Performance of a Down Draft Charcoal Gasifier", Applied Energy, 26 (1987) 193-216.

04. Amundson, N.R., "Solid Fluid Interactions in Fixed and Moving Beds". Ind. Eng. Chem. 1956b, 48, 35-43.

05. Amundson, N.R., "Solid Fluid Interactions in Fixed and Moving Beds". Ind. Eng. Chem., 1956a, 48, 26-35.

06. Schaefer, R.J., Vortmeyer, D., Watson, C.C. "Steady State Behaviour of

Moving Beds". Chem Eng.Sci.,1974,29,119-127.

07. Pedro. E. Arce et. al., "Heterogenious Model of a Moving Bed Reactor. 2. Parametric Analysis of the Steady State Structure". Ind. Eng. Chem. Res. 1989, 28, 165-173.

08. Groeneveld, M.J., "Production of A Tar Free Gas in an Annular Co-Current Moving Bed Gasifier".

09. Botterill, J.S.M. et. al., "The Effective Thermal Conductivity of High Temperature Particulate Beds - I, Experimental Determination". Int. J. Heat Mass Transfer, Vol. 32, No. 3, pp. 585-593, 1989.

10. Botterill, J.S.M. et. al., "The Effective Thermal Conductivity of High Temperature Particulate Beds - II, Model Prediction and the Implication of the Experimental Values". Int. J. Heat Mass Transfer, Vol. 12, No. 3, pp. 595-609, 1989.

11. Melanson, Maria, M. "Solid Conduction in Low dt/dp Beds of Spheres, Pellets and Rings". Int. J. Heat Mass Transfer, Vol. 28, No. 2, pp. 383-394, 1985.

12. Ulrich Graf, "Design Rules for Down Draft Gasifiers", GATE 1983.

13. Parikh, P.P., et. al., "Study of Thermal and Emission Performance of Small Gasifier - Dual - Fuel Engine Systems", Personal Communication.

14. Parikh, P.P., "Design and Development of a Wood Gasifier for I.C. Engine Applications - New Approach for Minimisation of Tar", Personal Communication.

NOMENCLATURE

A	Area of cross section	m^2
D	Column diameter	m
C_{ps}	Specific heat of wood	J/kgk
H	Heat of reaction	J/kg
E	Activation Energy	J/kmole
K_e	Effective thermal conductivity	w/mK
k_o	Arrhenios constant	1/s
L	Length of pyrolysis zone	m
M_s	Mass flow rate of solids	kg/hr
T	Temperature	
T_a	Ambient Temperature	k
T_o	Reference temperature	K
u_p	Linear velocity of solid phase	m/s
X	Conversion	
X_E	Maximum conversion	
Z	Axial coordinate	m
ϵ	Void fraction	

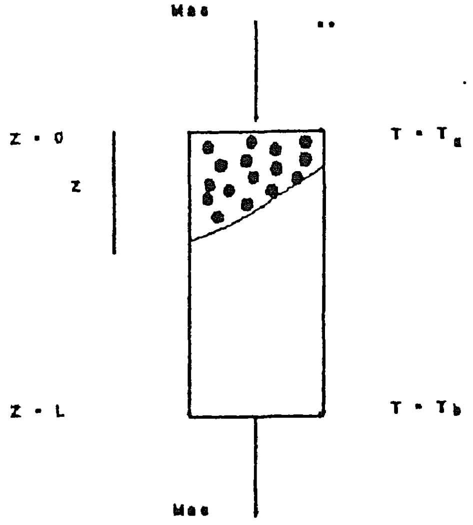

Fig.1 Pyrolysis reactor model

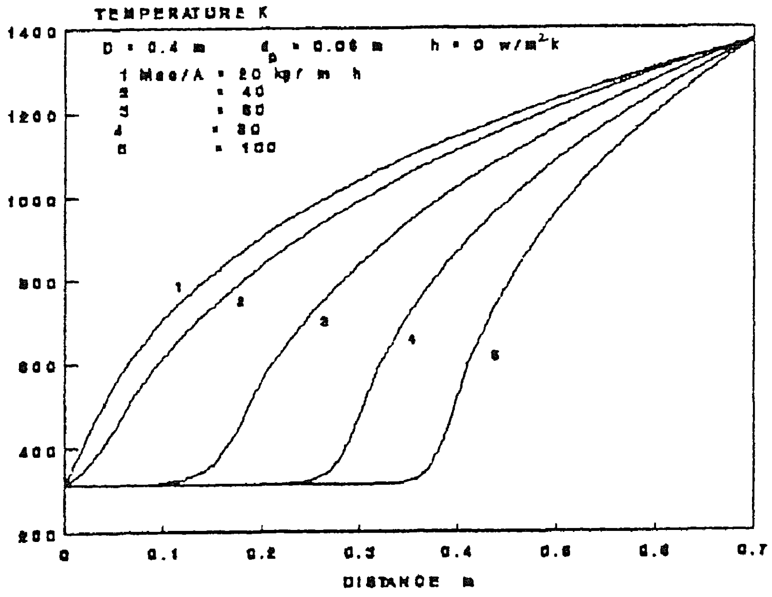

Fig.2 Effect of Mass velocity

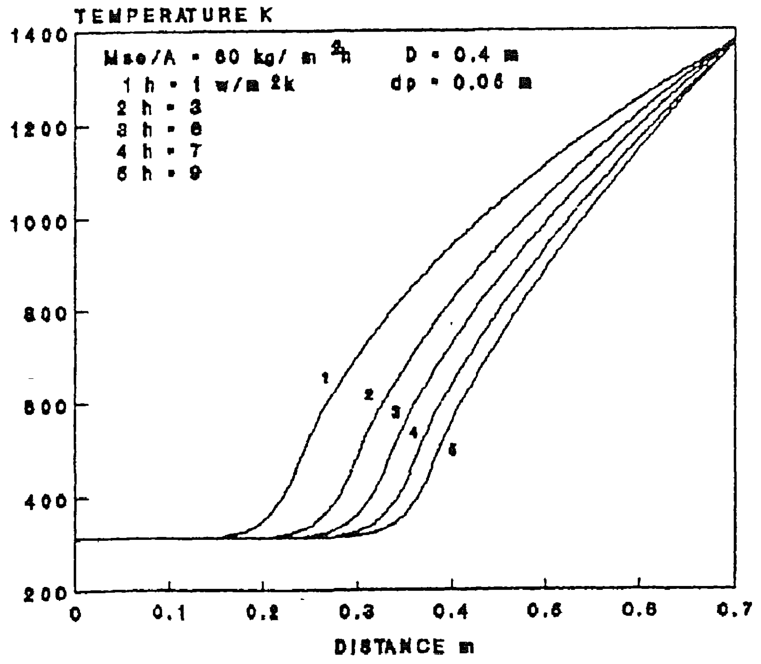

Fig.3 Effect of heat loss coefficient

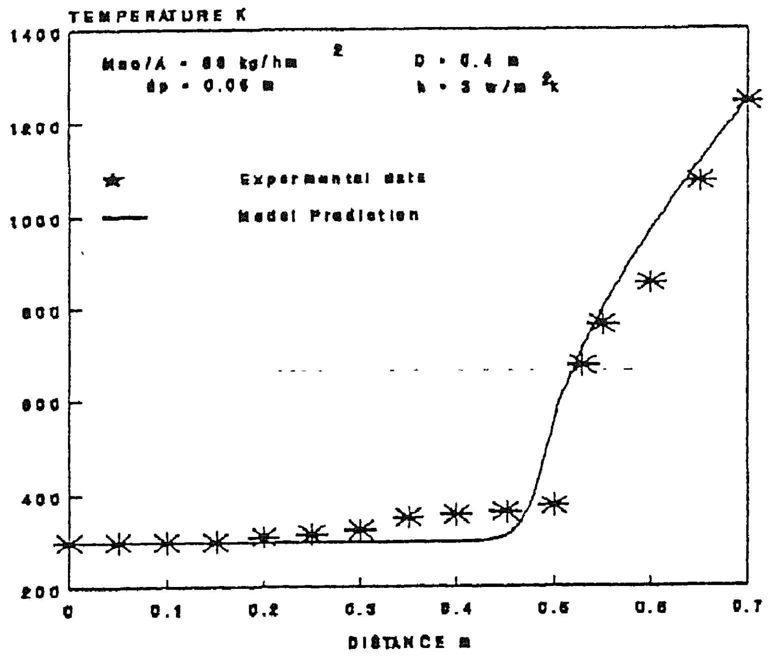

Fig.4 Comparison with experimental data

Proceedings of "The 1st National Meet on Recent
Advances in Biomass Gasification Technology"
at I.I.T. Bombay, Sept. 11-12, 1989, pp. 198-206.

Standardization of an Apparatus for the Estimation of Tar, Particulate and Moisture Contents in Producer gas

S.D. Sharma, P.Raman and V.V.N. Kishore
Tata Energy Research Institute,
232, Jor Bagh, New Delhi 110 003

ABSTRACT

An apparatus for the estimation of tar, particulate and moisture contents in the gas produced from a throatless downdraft biomass gasifier, had been designed, fabricated and tested. The particulate and tar were separated in the first step in a hot packed bed column of glass wool. In the second step the moisture and tar were stripped off the gas in a specially designed chilled ampule. The effect of different variables on the apparatus performance were studied.

INTRODUCTION

There is an increasing interest for gasifier operated, irrigation and power generation systems through I.C. engines. The implementation of the technology needs special attention in terms of producing and ensuring pure quality gas. The main contaminants as reported [1,2] in the gas are tar, dust and moisture. The adverse effects of these contaminants reflect in frequent maintenance requirements due to corrosion in inlet channels, valves, combustion chamber walls and piston crown which ultimately affect the engine's life [2]. Thus to ensure purity of the gas adequate for fueling I.C. engines it becomes extremely important to estimate the true contents of these contaminants. As reported in the literature [2] tar and dust are estimated in a sampling train where dust and tar are collected in different chambers at predecided temperatures. Particulates are separated from the condensate by solvent extraction and estimated gravimetrically. The use of THT method, which collects the condensate at 0°C and uses dichloromethane as the solvent, has been reported by the World Bank/UNDP programme on gasifier monitoring. A similar kind of dust and tar estimation technique had been used for testing gas quality at I.I.T. Bombay [2]. In the present work, an attempt had been made to estimate the contaminants in the gas using comparatively simpler techniques involving cheap and easily fabricable apparatus. The details of the technique along with preliminary experimental results are presented in the paper.

THE DESIGN AND DEVELOPMENT OF THE APPARATUS AND TECHNIQUE

The prime consideration in the development of the present technique was to avoid solvent extraction for separating tar and particulates because it adds complexity due to multiple handling and transferring of the contaminants. The design of the apparatus and technique had been evolved based on a number of experimental trials. The preliminary experimentation began with an apparatus similar to the sampling train. The dust and tar were separated in a hot packed bed of glass wool in the first step. The tar and moisture were condensed in a tar condenser where the gas was allowed to impinge on a cold surface. With this apparatus dust and tar were separated but the condensation of tar and moisture was not completed in a single step. Also, the capacity of the tar collector was found to be insufficient to accumulate all moisture in many instances.

The next apparatus had been designed to overcome the defects of the previous one. The dust collector bed was placed vertically above the tar collector to minimize the length of connections. A flask instead of a tube was used for collecting the tar and the gas was allowed to hit the wall of the flask tangentially so as to increase the time of contact with the cold surface. This design gave considerable improvement over the previous one but still some tar and moisture was observed to be escaping and collecting in the secondary tar collector connected in series. A tissue paper plug placed at the outlet of the flask was found to be effective in trapping the uncondensed tar. But since tissue paper, a cellulosic material, was hygroscopic in nature and might cause errors in estimation, it was decided to eliminate the use of tissue paper and modify the apparatus further.

In order to have effective condensation of tar it was necessary to achieve an efficient contacting between the gas sampled and the cold surface. In the final design (fig. 1) the gas was allowed to pass through a narrow (2-3 mm) annulus the outer wall of which was in direct contact with ice. A very fine sintered glass plate was placed at the outlet from where the gas was finally sucked by a vacuum pump through a wet flowmeter. This tar collector had been thoroughly tested for its effectiveness. The secondary condensors connected in series did not show any deposition of tar.

PROCEDURE

The estimation of particulates and tar was performed gravimetrically. The steps for one experiment were as follows.

(1) Initial weight of dry, particulate collector, tar collector, adopter and connecting tube were recorded.
(2) The apparatus was assembled and kept for 15-20 minutes for acquiring steady state with respect to temperatures in particulate and tar collector.
(3) One cubic meter of gas sample was drawn through the apparatus at a given flow rate. The flow rate was controlled with the help of a bypass valve placed at the outlet of the vacuum pump.
(4) Sufficient dry nitrogen was passed through the hot (300°C) bed of glass wool to flush out traces of tar condensed if any.
(5) The tar and dust collectors were brought to room temperaure and weighed.
(6) Both tar and dust collector were kept in an vacuum oven (at 100°C) for water evaporation. Both were cooled and weighed for the estimation of moisture, tar and particulate contents.

The deposition in the adopter and connecting tube was found to be less than 0.1 mg.

EFFECT OF VARIOUS PARAMETERS IN THE APPARATUS

Effects of different parameters such as the temperature of the particulate collector bed, bulk density of the glass wool, residence time in dust and tar collectors were obtained experimentally.

(1) Temperature of the dust collector : The temperature of dust collector was chosen on the basis of the reported [2] boiling points of the compounds present in tar. It was found that between 250°C to 300°C all compounds would be in the vapor state and hence would not be condensing in the dust collector.

(2) **Bulk density of the glass wool bed :** Bulk density of the packed bed was varied by increasing the mass of glass wool, keeping the volume of the container constant. The data collected shows fluctuations because of variation of the dust content in the source itself but nevertheless a qualitative inference could be drawn regarding the required bulk density for efficient dust collection. It was found that the bulk density should be above 0.08 gm/cc (fig. 2) for effective collection of all dust.

(3) **Residence time in the dust and tar collector :** The residence time of the gas in dust and tar collectors was varied by changing the volumetric flow rate of the gas sampled. The scatter of the points (figs. 3 and 4) was found to be too high to evolve suitable correlations but a few qualitative statements can be made: (a) For the chosen bulk density of the glass wool bed, the amount of dust collected is independent of the residence time in the range of residence times tried in the present experiment. (b) At very low values of residence times, characterised by high gas velocities, the scatter in tar contents is particularly high. This might be explained by assuming that at high gas velocities, some glass fibre is carried away into tar collecting flask by entrainment. (c) Residence times of 2 sec or more seem to be adequate for effective dust and tar removal.

TIME VARIATION OF TAR CONTENT

It had been experimentally found that the tar content in the raw gas decreases exponentially with time (fig. 5). This phenomenon is thought to be the main reason for the observed scatter in data. Experiments are under way to obtain data under steady state so that useful correlations could be developed.

ACKNOWLEDGMENTS

The work described in this paper has been carried out under a project entitled "Design, Fabrication, Testing and Field Demonstration of Biomass Gasifier Systems for Irrigation Pumping" (Ref. No. 203/12/86-BM), funded by the Department of Non-Conventional Energy Sources. The authors are thankful to Mr. Manjit Singh, Mr. Vellai Kannu and Mr. Gurvinder Singh for their assistance during the experimental work.

REFERENCES

1. I.S. Goldstein, Organic Chemicals from Biomass, CRC Press, Boca Raton, Florida, 1983, p 310.
2. P.P. Parikh, Measurement of Tar, Department of Mechanical Engineering, I.I.T. Bombay, Dec-1985.

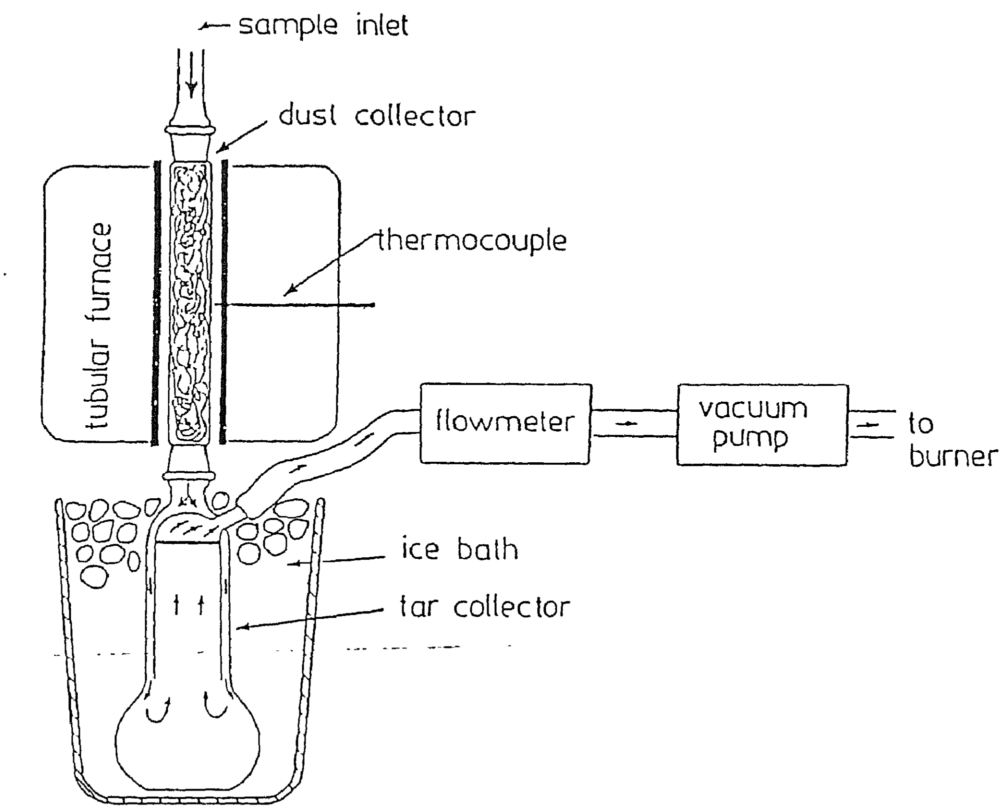

Fig. 1 Apparatus for the estimation of particulate, moisture and tar content.

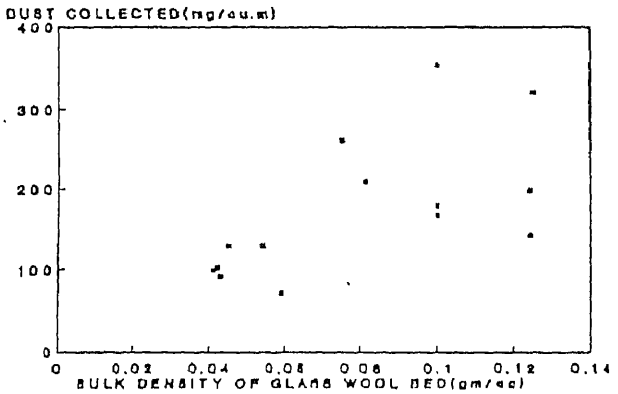

Fig.2 Effect of bulk density of the glass wool bed on the effectiveness of particulate collection

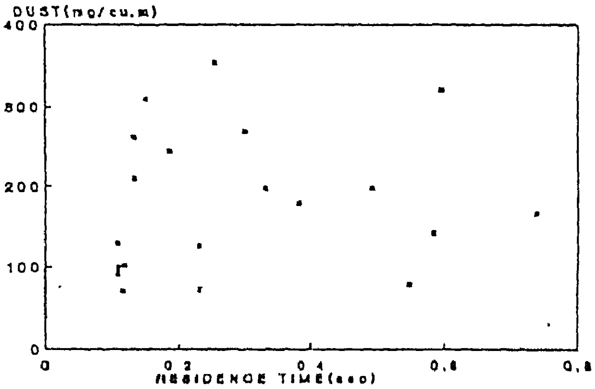

Fig.3 Effect of residence time on the effectiveness of dust collector

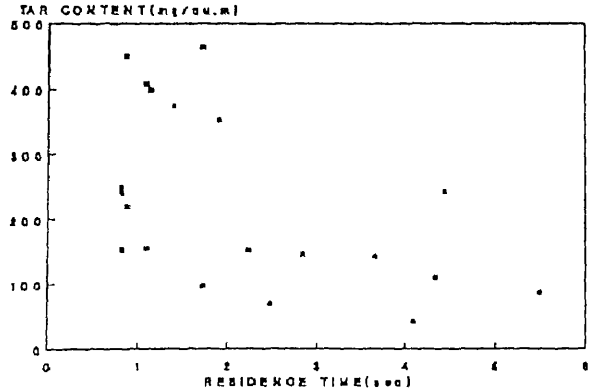

Fig.4 Effect of residence on the effectiveness of tar collector

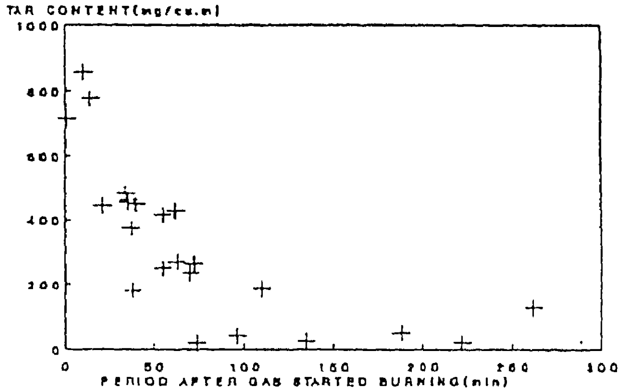

Fig.5 Variation of tar content with time

Evaluation of Performance of an Apparatus for the Estimation of Tar, Particulate and Moisture Contents in Producer Gas

S.D. Sharma and V.V.N. Kishore

Tata Energy Research Institute
232, Jor Bagh
New Delhi - 110 003.

Abstract

Performance of an apparatus for the estimation of tar, particulate and moisture contents had been tested in order to standardize the procedure for the evaluation of producer gas quality. The particulate and tar were separated in the first step in a hot bed of glass wool. In the second step tar and moisture condensed in a specially designed tar condenser. The effect of variables such as glass wool packed bed temperature, glass wool packed bed bulk density, residence time of sampled gas etc. were studied to set their limits to achieve accurate and reproducible results.

Introduction

There is an increasing interest for gasifier operated, irrigation and power generation systems through I.C. engines. The implementation of the technology needs special attention in terms of producing and ensuring pure quality gas. The main contaminants as reported [1, 2] in the gas are tar, particulate and moisture. The adverse effects of these contaminants reflect in frequent maintenance requirements due to corrosion in inlet channels, valves, combustion chamber walls and piston crown which ultimately affect the engine's life [2]. Thus to ensure purity of the gas adequate for fueling I.C. engines it becomes extremely important to estimate the true contents of these contaminants. As reported in the literature [2] tar and dust are estimated in a sampling train where dust and tar are collected in different chambers at predecided temperatures. Particulates are separated from the condensate by solvent extraction and estimated grevimetrically. The use of THT method, which collects the condensate at 0°C and uses dichloromethane as the solvent, has been reported by the World Bank/UNDP programme on gasifier monitoring. A similar kind of dust and tar estimation technique had been used for testing gas quality at I.I.T. Bombay [2]. In the present work an attempt had been made to evaluate the performance of a comparatively simpler technique for the estimation of the contaminants involving cheap and easily fabricable apparatus. The details of the technique along with the performance results are presented in the paper.

Principle of the Technique

The prime consideration in the development of the technique was to avoid solvent extraction for separating tar and particulates because it adds complexity due to multiple handling and transferring of the contaminants. The particulates and tar were separated in a hot packed bed column by eluting the hot column with dry air or nitrogen. The eluent which was mainly tar was condensed in a specially designed chilled ampule. The contents of tar, particulates and moisture were estimated grevimetrically.

Description of the Apparatus

The diagram of the apparatus is shown in fig. 1. The dust collector was a packed bed column (diameter = 2 cm, length = 20 cm) of glass wool. The whole glass wool bed was supported on a fine SS wire mesh placed at the lower end of the glass tube, in order to prevent the entrainment of glass fibres in to the sample gas. The column was placed vertically in a tubular furnace. The lower end of the column was fitted in to the inlet of the tar collecting ampule which was placed in an ice bath. In the tar collector the gas was allowed to pass through a narrow (2-3 mm) annulus the outer wall of which was in direct contact with the ice cold water. The narrow passage for the gas through annulus ensured the effective contacting between the gas sampled and the cold surface. A very fine sintered glass plate was placed at the outlet from where the gas was finally sucked by a vacuum pump through a wet gas flowmeter.

Procedure

The estimation of particulate and tar was performed grevimetrically. The steps for conducting one experiment were as follows.

1. Initially packed bed column of glass wool was washed with water in order to remove entrapped dust particles.
2. Initial weights of dry particulate collector with adopter, tar collector, and connecting tube were recorded. Drying and weighting performed several times till constant weights were obtained.

3. The apparatus was assembled and kept for 15-20 minutes for acquiring steady state with respect to temperatures in particulate and tar collector.
4. 250 litres of gas sample was drawn through the apparatus at given flow rate. The flow rate was controlled with the help of a bypass valve placed at the outlet of the vacuum pump.
5. Sufficient dry nitrogen was passed through the hot (300°C) bed of glass wool to flush out traces of tar condensed.
6. The tar and dust collector were brought to room temperature and weighed.
7. Both tar and dust collector were kept in a vacuum oven (at 100°C) for water evaporation. Both were cooled and weighed for the estimation of moisture, tar and particulates content.

The deposition in the connecting tube was found to be less than 0.1 mg.

Performance Results and Discussion

As reported in earlier paper [3] that the tar content in the raw gas decreases exponentially with time (fig. 2). This variation was probably due to the unsteady state of the fire box with respect to the temperature. A constant and sufficiently high temperature is attend in the fire box only after about 2 hours of operation, which probably helps in efficient cracking of tar. Thus for evaluating the performance of the apparatus it was decided to conduct all the experiments in the time region where tar content in the gas was maintaining some consistency. Since other factors such as fuel bed height in the gasifier, suction through the gasifier etc. could influence the tar content in the gas were also maintained constant. The effect of different parameters such as the temperature of the particulate collector bed, bulk density of the glass wool bed, residence time of the gas in dust and tar collectors were obtained experimentally.

1. Temperature of the dust collector

The temperature of dust collector was chosen on the basis of the reported [2] boiling points of the compounds present in tar. It was found that between 250°C to 300°C all compounds would be in the vapour state and hence would not be condensing in the dust collector.

2. Bulk density of the glass wool bed

Bulk density of the packed bed was varied by increasing the mass of glass wool, keeping the volume of the container constant. Fig. 3 shows the variation of dust collection effectiveness with the bulk density. The bulk density between 0.2 to 0.35 had been finally selected for further experimentation because in this reasons (fig. 3) the effectiveness of dust collection showed a maximum and consistent magnitude.

3. Residence time in the dust and tar collector

The residence time of the gas in dust and tar collector was varied by changing volumetric flow rate of the gas sampled. For dust and tar collection (fig. 4 & 5) the effect of residence time would be said to be negligible. The tar content plotted in fig. 5 was normalized for the effect of time on tar content (fig. 2). It is obvious that the residence time between 3 to 7 second for tar collection and 0.06 to 0.085 second for dust collection could be chosen as suitable limits for experiments.

Precision of the technique

During all the experiments, although the controllable variables were maintained at the same level but the humidity of the atmosphere, moisture content in the different lots of the fuel varied up to some extent. However, the account of such variables did not made in the present set of experiments. The average values of moisture, tar particulate contents in the gas along with the standard error are given in the table 1, which signifies the precision of the measurements.

Table 1

Contaminants	Average composition of contaminants in raw gas	Standard error
Moisture	69.73 gm/cu.m.	± 12.08
Particulate	79.25 mg/cu.m.	± 6.11
Tar	59.87 mg/cu.m.	± 7.93

References

1. I.S. Goldstein, Organic Chemicals from Biomass, CRC Press, Boca Raton, Florida, 1983, p 310.
2. P.P. Parikh, Measurement of Tar, Department of Mechanical Engineering, I.I.T. Bombay, Dec-1985.
3. S.D. Sharma, P. Raman, and V.V.N. Kishore, Standardization of an Apparatus for the Estimation of Tar, Particulate and Moisture Contents in Producer Gas, YSF - 8/198. 1989.

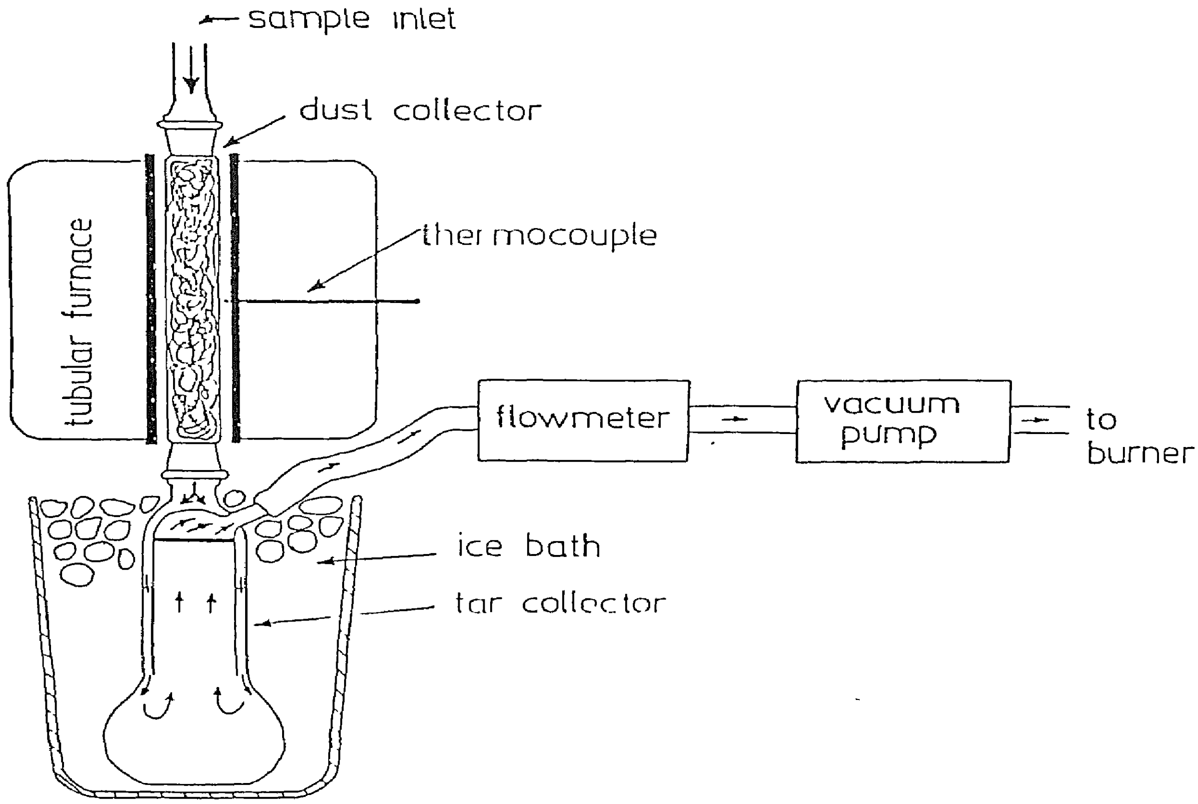

Fig. 1: The Apparatus

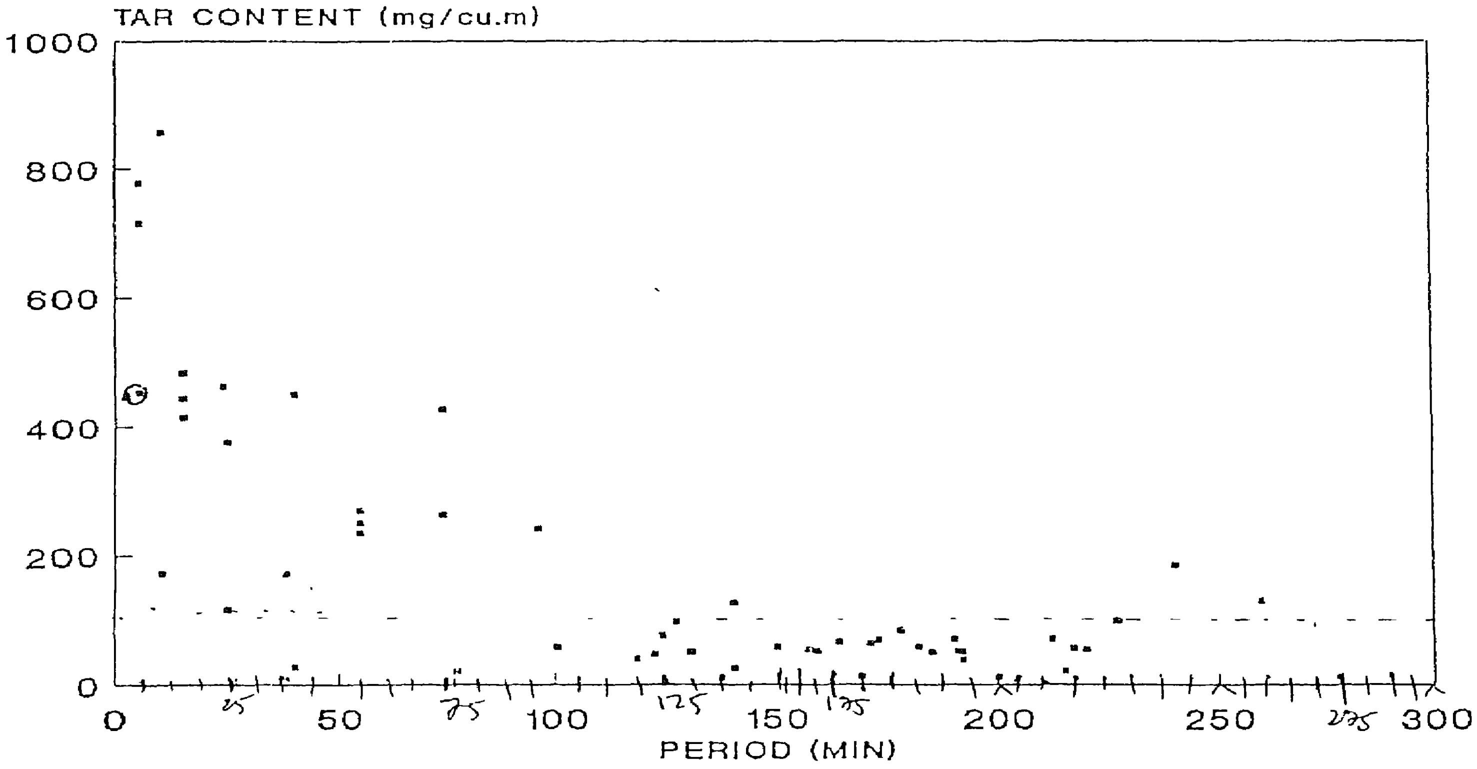

Fig. 2: Variation of Tar Content with Time

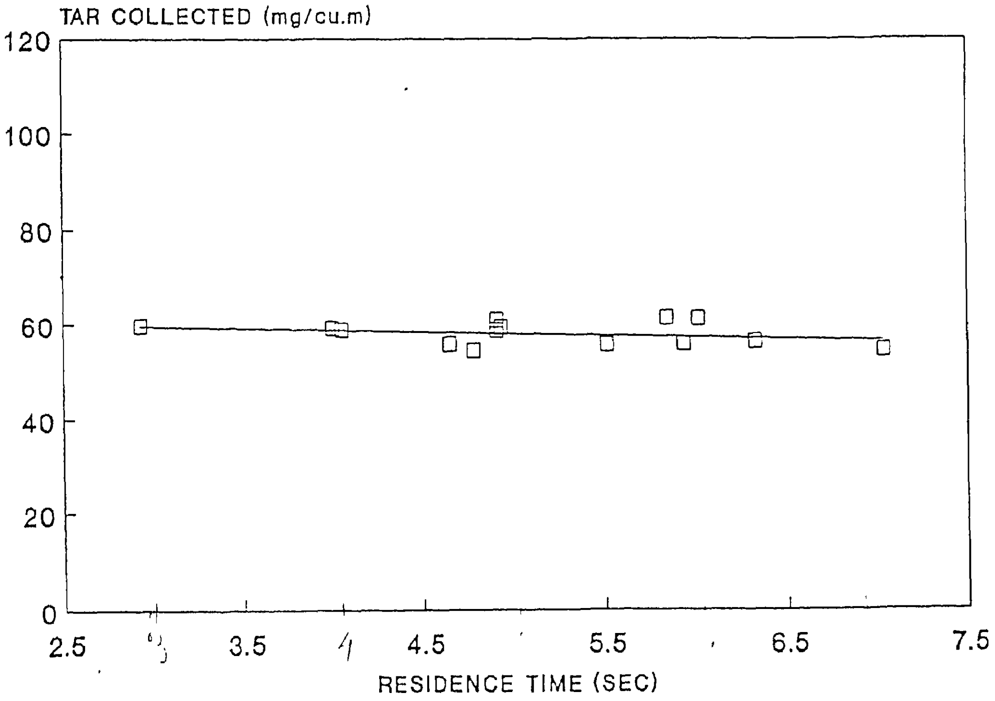

Fig. 5: Effect of Residence Time on Tar Collection

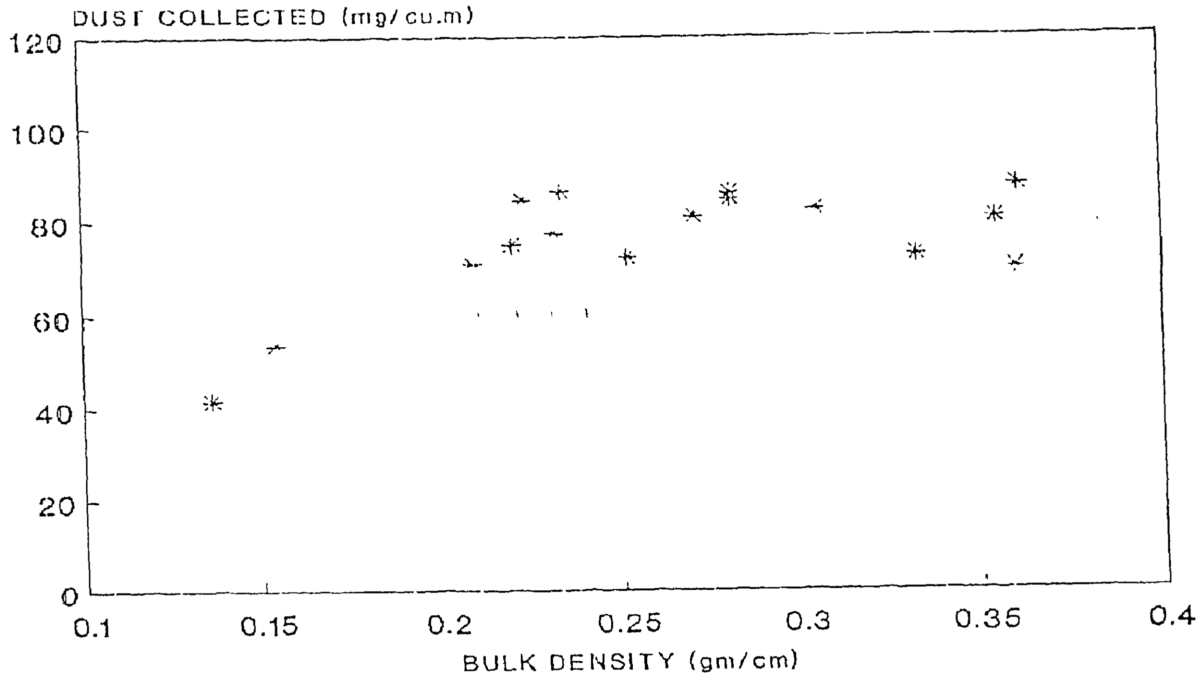

Fig. 3: Effect of Bulk Density on Dust Collection

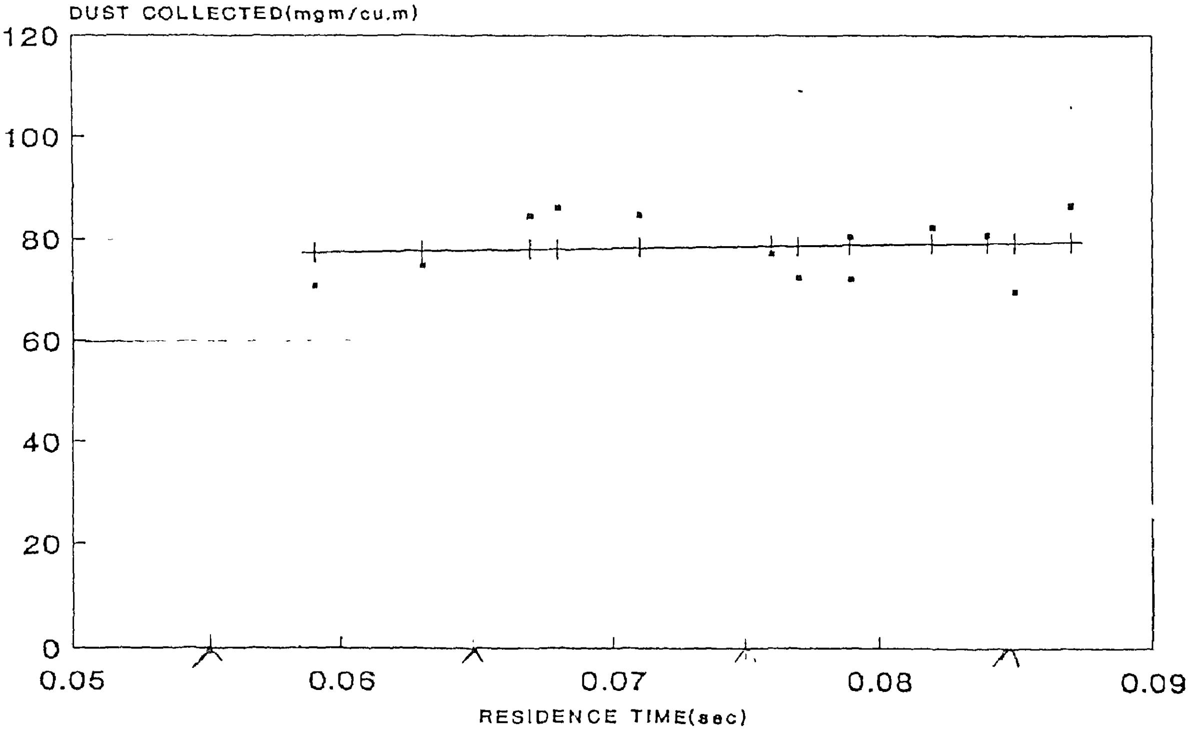

Fig. 4: Effect of Residence Time on Dust Collection

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at I.I.T. Bombay, Sept. 11-12, 1989, pp. 61-65.

STUDIES ON A BRIQUETTING - GASIFICATION SYSTEM FOR UTILIZATION OF BIOMASS RESIDUES

P. Raman, S.D. Sharma, V.V.N. Kishore
Tata Energy Research Institute
7 Jor Bagh, New Delhi - 110 003

ABSTRACT

A motive power generation system employing the briquetting-gasification route has been developed and tested. Production of biomass briquettes consists of (i) pulverization (where warranted) (ii) briquetting in a low pressure extruding type machine using biogas plant effluent slurry as binder and (iii) sun drying. The gasifier and the associated cooling-cleaning train with several novel features has been described in detail. Analysis of gas including gas composition, tar, particulate matter and moisture, has been carried out. A 5 H.P. diesel powered irrigation pump has been coupled with the gasifier and entire system has been tested using firewood and biomass briquettes. Diesel replacement values in excess of 60% have been obtained with all the fuels tried.

1. INTRODUCTION

The importance of gasification as a technology for effective utilization of biomass residues need not be overemphasized. However, reports of gasification of biomass other than wood are few. Gasification of rice hulls has been studied rather extensively [1], but similar studies on other biomass residues such as saw dust, groundnut shells, coconut husk, cotton stalks, mustard stalks, etc. are almost non-existent.

There is a general consensus among researchers that the design of a gasifier is highly fuel-specific, but this point has not been elaborated. Barring a few high-ash materials such as rice husk, straw etc., several residues have similar properties in relation to proximate analysis, calorific value, ash content and devolatilization [2,3]. The single major problem of using these residues in a down-draft gasifier would then be related to control of the mass flow rate inside the reactor. Briquetting (or densification) of such materials can result in the production of fuel with a uniform shape and size which can be gasified in suitable down-draft gasifiers. Thus the briquetting-gasification route can be seen as a potential means of generating motive power from several, if not all, biomass residues.

A method of charring, briquetting and gasification of biomass has been developed by earlier workers [4]. In the process developed in the present work, the pre-treatment of biomass consists of pulverization (if needed), briquetting and sun-drying. The design details of the gasifier, cooler and filter are described in detail elsewhere [5]. The present paper gives the results of trials conducted on several biomass residues such as saw dust, coconut pith, mustard stalks, bajra stalks and groundnut shells.

2. THE BRIQUETTING SYSTEM

Two methods of briquetting are in vogue at present. One consists of subjecting the biomass to a very high pressure (1200 kg/sq.cm), and is known as binderless briquetting. The density of briquettes obtained is fairly high, and the machines are commercially available. The second method consists of adding a binder, such as molasses, to the loose fuel particles and extruding the mixture at low pressures (200 kg/sq.cm). The resulting briquettes have a lower bulk density. This process, however, has so far been applied to char or coal dust, using molasses, clay etc. as binding agents. In the present work, the method has been successfully adopted for pulverized biomass, using biogas plant effluent slurry as binder. A commercially available pulverizer with a 5 H.P. drive has been used for size reduction of biomass. Groundnut shells, bajra stalks and mustard stalks have so far been pulverized successfully. A commercially available low-cost, low-speed, coal dust briquettor driven by a 5 H.P. motor has been modified suitably to produce briquettes of biomass. The powdered biomass is mixed well with biogas plant effluent slurry in suitable proportions and the resulting semi-solid is fed into the briquetting machine. The cylindrical briquettes obtained (1 "dia.) were collected in trays and sun-dried for later use. The specific electricity consumption varies with the type of biomass, and is yet to be measured accurately, but it is of the order of 0.1 kWh/kg (dry), including both the steps of pulverization and briquetting. The properties of briquettes prepared in this work are summarized in Table 2.1.

3. THE GASIFIER-ENGINE SYSTEM

The details of the gasifier unit are shown in fig. 3.1. It is a throatless, down-draft design with a very low specific gasification rate of 0.032 Nm3/(cm2)(hr) which facilitates bulk flow of the fuel inside the reactor. The combustion-gasification zone is insulated with glass wool in order to achieve high reaction temperatures. Two horizontal S.S. nozzles and one central nozzle have been provided for air inlet. An MS grate connected with a shaking arm is coupled to a reciprocating device through a hermetically sealed bellow coupling for continuous ash removal. A manually operated ribbon-type helical coil is provided for occasional agitation of the fuel bed. The gas produced passes through the annulus formed by the outer edge of the insulation and the outer cover of the gasifier in order to achieve gravity-settling of coarse particulate matter.

The equipment used for cooling and condensation of tar is shown in fig. 3.2. It consists of a rectangular G.I. trough filled with water with a bottomless, rectangular, G.I. gas holder placed inside the trough. The upper portion of the gas holder has a sloping surface and has projections on all four sides so as to form a tray. Water is filled in this tray. The raw gas passes through the narrow channel formed by the surface of water in the trough on the one side and the cool, metal surface of the tray on the other. Tar condensed on the cool, sloping surface of the upper tray trickles down into the water bed. The cooler is a passive device, requiring no attention for many days. The temperature of the cooled gas is of the order of 40 deg.C. The pressure drop across the cooler is less than 1 cm water column.

A multi-pass filter with nylon meshes and an oil bath, shown in fig. 3.3, is provided for collection of fine particles in the gas. The cleaned gas is fed into a 5 H.P. diesel engine through a carburettor. A carburettor is not used normally in diesel engines, but it has been found to be very effective in achieving a very good mixing of producer gas with air, resulting in lesser derating and reasonably good diesel replacements even with a low quality gas.

4. METHODS OF ANALYSIS

The chemical composition of the product gases has been measured by means of an orsat apparatus. The apparatus developed for measuring the tar, dust and moisture content of the gases is described in detail elsewhere [5]. Briefly, it consists of passing the gases through (i) a glass wool filter kept at a high temperature (200 deg.C) for dust removal and (ii) a glass container kept at low temperatures (0 deg.C) for tar and moisture removal. The estimation of tar, dust and moisture is by gravimetric methods. A minimum of 1 cu.m of gas was processed for each measurement. Diesel consumption was measured by means of a burette and temperatures were measured either by thermocouples or thermistors.

5. RESULTS

The composition of the producer gas obtained from various fuels is shown in Table 5.1. The results of tar, dust and moisture measurement are shown in Table 5.2. It can be seen that the particulate matter is higher for briquetted biomass with binder than for other fuels. This might be due to disintegration of briquettes combustion. This problem can be solved by providing a cyclone separator. The time variation of tar content in the raw product gases is shown in fig. (5.1). It should be mentioned that sampling was done after burning gases were obtained. Figure 5.1 clearly shows that the tar content decreases exponentially with time and that it takes a long time to achieve equilibrium conditions in the gasifier.

The diesel replacement values obtained with various fuels are given in Table 5.3. It can be seen that diesel replacement values in excess of 60% were obtained with all the fuels tried. The gasifier used in these studies suffered from two disadvantages: a low gas residence time and a large hopper volume. A second gasifier overcoming these defects and with improved design features has now been fabricated and would be tested shortly. The gasifier, cooler, filter, diesel engine, pulverizer, briquetting machine and an alternator are now being assembled on a portable trolley and testing of various components is in progress. In this prototype, the pulverizer and briquetting machine would be operated from the gasifier-coupled diesel engine directly, requiring no use of electricity. The prototype, after thorough testing in the lab, would be shifted to a village for further field testing.

6. CONCLUSIONS

A system employing briquetting and gasification for generation of motive power has been designed, fabricated and tested. Using biogas effluent slurry as binder, briquetting of saw dust, coconut puth, mustard stalk (pulverized), bajra stalk (pulverized) and groundnut shell (pulverized) has been accomplished successfully. A throatless, downdraft gasifier with a continuous ash removal facility has been fabricated and tested with wood chips and biomass briquettes. Burning gas has been obtained with all the fuels tried in the same gasifier. A passive gas cooler cum tar separator has been fabricated and found to perform satisfactorily. A 5 H.P. diesel powered irrigation pump has been coupled to the gasifier and diesel replacements of 60% or more had been obtained for all the fuels tried.

ACKNOWLEDGEMENTS

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REFERENCES

1. A. Kaupp, Gasification of Rice Hulls, GATE Publication, Eschborn, FRG (1984).

2. S. Kohli, P. Raman and V.V.N. Kishore, Evaluation of Various Fuels for Gasification, Energy Options for the 90s, N.K. Bansal, V.V.N. Kishore and Anil Misra (eds), Tata Mc. Graw-Hill, New Delhi, pp. 508-514 (1988).

3. P.D. Grover et. al, Thermo-chemical Characterisation of Biomass for Gasification, IIT, Delhi (1988).

4. Siddhartha Gaur et. al, Preparation of Agro-residues for Gasification and Domestic Applications, paper presented at the National Workshop on Biomass Conversion Processes held at Punjab Agricultural University, Ludhiana (1986).

5. P. Raman, S.D. Sharma, S. Kohli and V.V.N. Kishore, Design and Test Performance of a Throatless Down-draft Gasifier with a Low Specific Gasification Rate, Renewable Energy for Rural Development, V.V.N. Kishore and N.K. Bansal (eds), Tata Mc Graw-Hill, New Delhi, pp. 568-573 (1989).

Table 2.1 : Properties of biomass briquettes.

Briquetted biomass	True density (kg/cu.m)	Bulk density (kg/cu.m)	Moisture content (%)	Volatile matter (%)	Ash (%)	Fixed carbon (%)
Saw Dust	273±17	252±1	3.2	63.0	18.9	14.9
Bajra stalk	297±13	250±1	3.5	62.6	15.4	18.5
Mustard stalk	378±13	198±1	3.7	70.0	12.3	14.0
Coir pith	254±14	228±1	4.3	58.3	19.2	18.2

Table 5.1 : Fuel composition (% by volume).

	CO	H2	Cn Hm	O2	CO2	N2
Wood chips (15 points) (15 points)	13.8±1.2	12.4±1.5	0.4±0.6	0.4	12.9±1.2	59.±1.8
Saw dust * binderless (3 points)	10.3±1.3	13.6±2.2	1.0±0.2	0.5	15.6±2.7	59.1±0.9
Saw dust * with binder (3 points)	8.1±0.2	14.5±0.5	0.0	0.0	16.5±0.6	61.0±1.2
Coir pith * with binder (2 points)	8.8±0.1	8.5±1.7	1.1±0.7	0.0	15.8±1.0	65.9±1.7
Mustard stalk * with binder (1 point)	7.9	13.4	0.2	0.1	15.9	62.5
Bajra stalk * with binder	Burning gas obtained.		Measurements yet to be made.			
Groundnut shell * with binder	Burning gas obtained.		Measurements yet to be made.			

* Briquettes

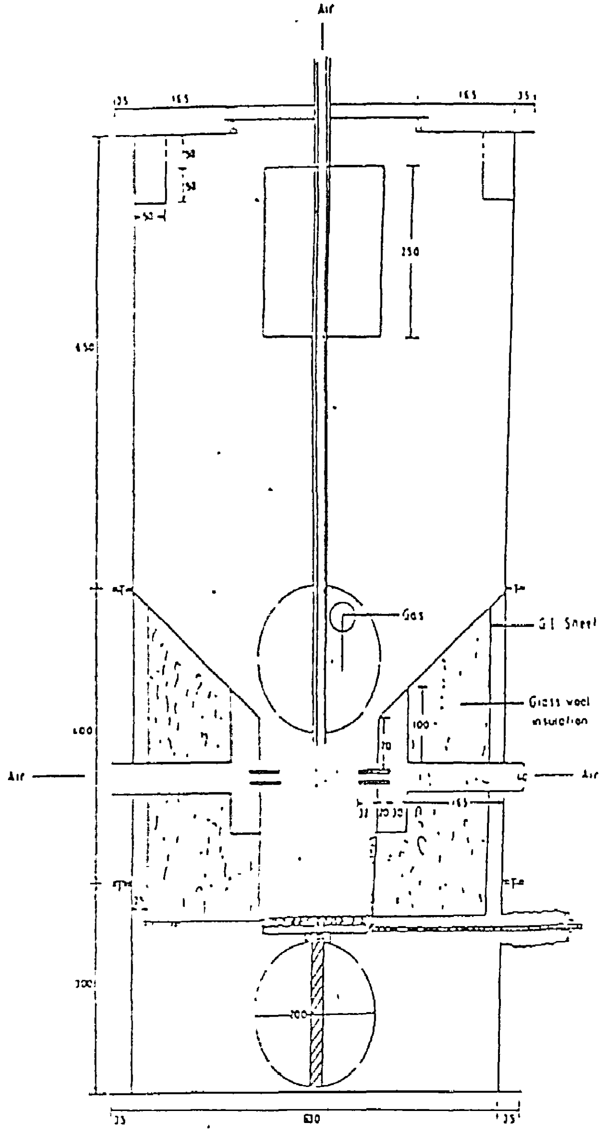
Table 5.2 : Tar, particulate, and moisture contents in the gas.

S.No. No.	No. of measurements	Fuel	Sample Position	Tar (mg/Ncu.m)	Particulate (mg/Ncu.m)	Moisture (gm/Ncu.m)
1	6	Wood	Raw gas	89.6-145.2	22.0-138.8	19.0-20.0
2	7	Wood	After cooler	7.0-37.0	6.0-25.0	1.0-7.6
3	1	Saw dust *	After cooler	18.5	11.5	1.0
4	1	Saw dust *	After cooler	-	446.4	1.0
5	1	Coir pith *	After cooler	75.0	494.4	1.0

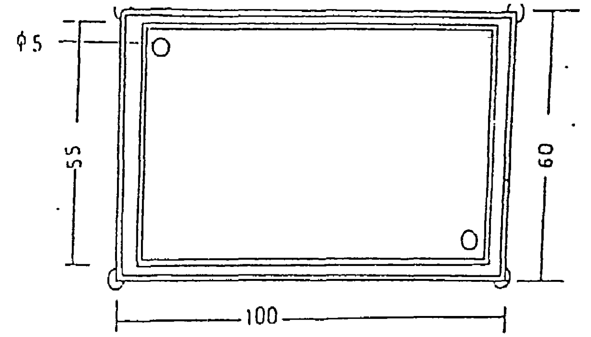
* with binder

Table 5.3 : Diesel replacement values with various fuels.

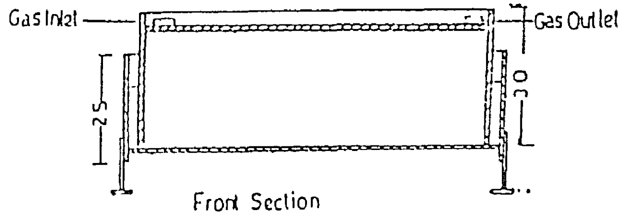
Fuel	Diesel replacement (%)	Approximate hours of operation
Wood	65-70%	150
Saw dust briquettes (binderless)	60-65%	20
Saw dust briquettes (with binder)	67%	15
Mustard stalk briquettes	Not measured	



BO-MASS GASIFIER

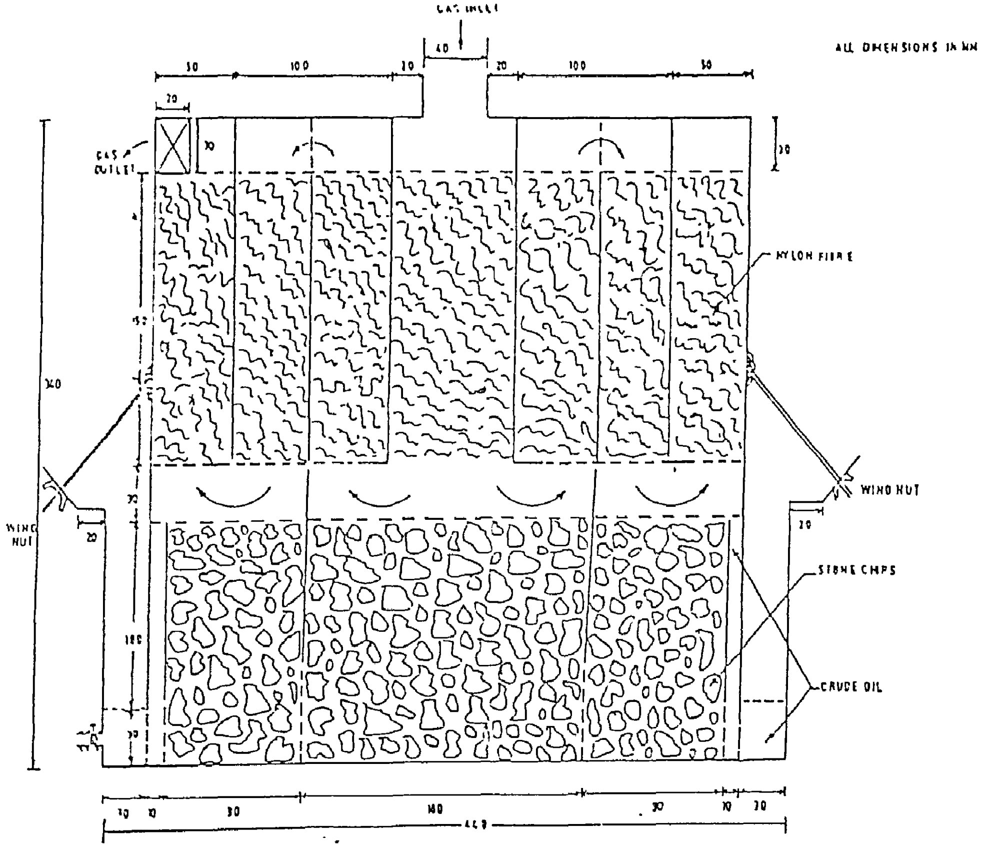


Top Plan



Front Section

GAS COOLER



DUST FILTER

Proceedings of "The 2nd National Technical Mee
on Recent Advances in Biomass Gasification
Technology" at Renewable Energy Centre, Udaipu
Dec. 20-21, 1990, pp. 99-119.

A MULTIFUEL, MULTIPURPOSE, PROTOTYPE BIOMASS GASIFIER SYSTEM - DESIGN AND PERFORMANCE DETAILS

P. Raman, Sunil Dhingra and V.V.N. Kishore
Tata Energy Research Institute
232, Jor Bagh, New Delhi - 110 003

ABSTRACT

A biomass gasifier system with fuel and end-use flexibility has been designed, fabricated and field-tested. The system is based or use of fuel briquettes in the gasifier which in turn powers a diesel engine. The diesel engine provides shaft power for driving a number of devices such as a chopper, pulverizer, briquetting machine and ar alternator.

The gasifier accepts briquettes of mustard stalk, saw-dust groundnut shell etc. apart from wood chips. The design an performance details of the system are described in this paper.

INTRODUCTION

The viability of utilizing several biomass residues i briquetted form in the same gasifier had been demonstrated earlie [1]. In the system described in Ref [1], pulverization of biomass briquetting of biomass and grate-shaking of the gasifier wer accomplished by use of electrical motors. In order to perform thes operations without using electricity and to demonstrate the viabilit of the gasifier system in field conditions, the various subsystem have been assembled on a mobile unit and installed in a village i Haryana. This paper describes the design and performance details o the complete system.

DESCRIPTION OF THE SYSTEM

A schematic diagram of the complete system is shown in Fig. 1 The system consists broadly of (i) the main gasifier unit wit associated cooling-cleaning train (ii) the prime mover wit associated torque-transmitting system and (iii) variou accessories/end use devices driven by the prime mover. Thes devices are a) a chopper b) a pulverizer c) a briquetting machine ar d) a 7.5 kVA alternator, and are coupled to a common shaft throug belt drives. Flat belts are used for easy removal and coupling. Th combined horse power of all these devices is more than 10 H.P., bu when operated separately, the horse power requirements of each i well within 10 H.P. Except the generator which can take electri loads upto 5 kW, the other devices have power rating less than 5 kW tems such as the alternator, chopper, pulverizer, blower, gear box nd diesel engine have been procured locally and the rest have been abricated. The diesel engine also drives the radiator fan, coolant ump and the grate shaking device which are always in operation as ong as the engine is running. Several attempts had been made to run he blower directly from the diesel engine shaft, but were iscontinued due to non-availability of suitable blowers. The blower s currently operated by electricity generated by the alternator. he biomass used for most of the time was mustard stalks. The rocessing of mustard stalk consisted of chopping, pulverizing, riquetting, and air drying, in that order. Saw-dust obtained from a aw-mill factory in a nearby village was also used as fuel ccasionally. Saw-dust can be briquetted directly, without going hrough the operation of chopping and pulverization. An electrically perated circular saw was also used for cutting mustard stalks, but as been replaced by the chopper as the output of the saw was very ow. In regular operation, the gasifier is loaded with briquettes, he diesel engine and blower started, and the bed is then ignited by flaming torch. A few minutes after burning gas is obtained, the as is diverted to the diesel engine and the blower switched off. epending on the requirement at hand one of the various devices riven from the main shaft is operated. The system is installed on a ite which is close to the village temple. The temple has a total oad of 1.8 kW, used for fans and lights. The site itself has some ube lights installed. Some excess capacity is still available and his will be used for powering some streetlights in the village. etails of different components of the system are described below.

. The Gasifier

A diagrammatic sketch of the gasifier is shown in Fig. 2. t is a downdraft, throatless design with a low specific gasification ate and has provision for continuous ash removal. The fire box combustion-reduction zone) is made with SS310 and has a composite nsulation, the inner core consisting of Supercrete and the outer ayer consisting of glass wool. The thickness of each layer was ecided from calculated temperature profiles and acceptable emperatures for each material. This design allows for larger fire ox diameters without compromising on the temperatures attained in he combustion-gasification zone. The gas generated passes through he grate and up through the annular space shown, transferring some f the sensible heat to the fuel bed, and finally exits in a angential manner at the top of the gasifier. The outer shell, made f MS is insulated with glass wool. A spiral agitator was originally rovided in the fuel bin as shown, but was removed later as the fuel ovement was adequate. The advantages of the present design are hought to be i) a better control of temperature in the fire box i) a better fuel movement within the gasifier iii) flexibility f fuel holding capacity and iv) acceptability of high-ash fuels. he design also allows for some degree of particulate removal within he gasifier.

2. The Ash Removal System

A schematic diagram of the ash removal system is shown in Fig. 3. A reciprocating device (actually a piston pump, with the pump removed) driven directly from the diesel engine shaft, is connected to the grate by means of a connecting arm. The connecting mechanism is hermetically sealed by use of a bellow coupling, to ensure prevention of air leakages into the system. The frequency of shaking is decided by the ratio of the diameters of the pulleys connecting the engine and the reciprocating device, which can be changed at will. The frequency of shaking for the present system is 4 cycles per second.

3. The cyclone Separator

Details of cyclone separator are shown in Fig. 4. This was not provided in the first prototype described in ref [1], but as the particulate matter in the gases obtained from several biomass briquetters was significant [1], the cyclone filter was introduced in the second prototype. The design efficiency of the cyclone is 85-92% (for particle sizes of 5μ-10μ).

4. The Cooler

The operating principle of the cooler is described earlier [1,2]. Briefly, the tar-ladden gas is allowed to pass through a rectangular channel formed by a lower water layer and an upper cold metallic surface kept in contact with water. The water temperature is initially close to the wet-bulb temperature, but increases upto about 40^{o}C during prolonged operation. These temperatures are sufficient to cause condensation of tar on the upper metallic surface, which is at a slight inclination allowing the condensed matter to flow into the trough of water. The water surface will also absorb some tar directly. The water in the trough has to be changed once in a while, but not too frequently. The cooler thus serves the dual purpose of cooling the gas and separating the tar in a simple way. It has to be mentioned that due to the high temperatures attained in the gasifier, the tar content of the raw gas itself is quite low (lesser than 150 $mg/N\ m^3$ at steady state). Figure 5 gives the details of the cooler.

5. The Dust Fitter

The details of the dust filter are shown in Fig. 6. The gas enters an oil chamber through a central inlet and exits tangentially. The oil surface collects the dust contained in the gas impinging on it. Several nylon meshes were used in the earlier design [1], but were found to be not needed and hence removed later.

6. The Prime Mover and the Power Transmission System

As stated earlier, the prime mover is a 10 HP diesel engine of a local make. Actually a 7.5 KVA diesel genset was procured locally and the alternator and engine were then separated. In order to achieve the assembly in the desired condition, several changes had to be made. The radiator had to be removed and fixed at a higher level and a separate pulley system had to be fixed on the shaft of the diesel engine. The main shaft houses several pulleys from each of which torque can be transmitted. The diameters of various pulleys are selected so as to obtain the proper rpm required for each of the machines. The calculations for the alternator are shown below as an example.

If N_1 and N_2 are the rpm values of the pulleys coupling diesel engine shaft and the main shaft and r_1 and r_2 are the corresponding radii, then

$$N_1 r_1 = N_2 r_2$$

or

$$N_2 = N_1 . r_1 / r_2 .$$

If r_3 and r_4 are the radii of the pulleys coupling the main shaft and the alternator, the rpm of the alternator, N_4 is given by

$$N_4 = N_2 (r_3/r_4)$$

$$= N_1 (r_1/r_2) (r_3/r_4)$$

Both the alternator and engine are designed to run at the same speed, and hence N_4 should be equal to N_1. The various radii have then to be selected in such a way that

$$\frac{r_1}{r_2} \; \frac{r_3}{r_4} = 1$$

The calculations for the other machines have been made in a similar way.

7. The Briquetting Machine

The details of the briquetting machine are shown in Fig. 7. It is basically a screw extruder type, and is a modified version of the machine described in ref [1]. The original machine, procured from Chandigarh, was meant for making briquettes from coal dust. For operation with pulverized biomass, the machine was redesigned and fabricated locally. The changes include i) reducing the clearance between the auger and the cylinder walls, ii) providing ball bearings to reduce wobble and iii) use of a gear box (1:7 reduction). These changes resulted in a compact arrangement and smooth operation. The pulverised biomass is mixed in suitable proportions with biogas slurry or dung and fed into the hopper. The briquettes produced are collected in trays, air dried and stored in G.I. containers for later use.

The entire assembly as viewed from different angles is shown in Figs. 8-10.

PERFORMANCE OF THE SYSTEM

The existing gasifier literature is replete with statements which do not recommend the operation of downdraft gasifiers at low specific gasification rates because the temperatures achieved in the fire box are lower and hence the tar content of the gases is higher. The situation is quite different when the fire-box is properly insulated. Figure 11 shows the temperature variation at the centre of the combustion zone after initial ignition. The temperature values are not very accurate as the sensor used ('.J' Type-termocouple) is not recommended for use at temperatures above $1200^{\circ}C$, but it is obvious that temperatures in excess by $1200^{\circ}C$ are obtained in the fire box. Figure 12 shows the temperature history after the blower was stopped. The slow rate of cooling is indicative of the effectiveness of insulation. Figures 13-16 show the radial variation of temperature with different fuels at different gas flow rates corresponding to different biomass flow rates. It can be seen that temperatures above $1200^{\circ}C$ are obtained for specific gasification rates ranging from 0.03-0.10 Nm^3/cm^2-hr, which are much lower than the recommended values of 0.5-0.9 Nm^3/cm^2-hr. The radial temperature distribution is seen to be improving with increased gas flow rates and for the rate of 20 Nm^3/hr, approaches an almost plug-flow condition. The vertical temperature profile in the gasifier is shown in fig. 17. Gas composition and tar and dust content values have been reported earlier [1]. Performance of the cooler and dust filter have also been reported earlier. The pressure drops across the various components of the gasifier system are as follows :

Δp across cyclone separator : 10 mm

Δp across cooler : 07 mm

Δp across dust filter : 25 mm

The diesel consumption values for diesel mode and dual-fuel mode are shown in fig. 18 as functions of load. The diesel replacement values are shown in fig. 19.

Briquetting is usually considered as an energy intensive operation. This is not true from the point of overall energy balance in conjunction with electricity generation. Data from various types of briquetting plants indicate a specific electricity consumption of about 0.1 kWh/kg for power briquetting. As the specific electric generation from gasifier based systems is known to be about 1 kWh/kg, it can be seen that only about 10% of electricity generated is consumed for briquetting. In the present case, due to the lower density of briquettes, the energy consumption figures are even lower. The various figures obtained for processing of mustard stalks into fuel briquettes are summarized in Table 1. The total diesel consumption in the diesel mode comes to about 0.025 lit/kg. At the rate of 4 Rs/lit, the fuel cost of conversion of stalks into briquettes works out to 10 paise/kg. In the dual fuel mode, the diesel consumption is about 0.007 lit/kg and the cost of conversion works out to about 3 paise/kg.

The system has so far logged 350 hours, out of which 200 hrs. were in laboratory and 150 hrs were in the field.

ECONOMIC CONSIDERATION AND POTENTIAL USES OF THE SYSTEM

The cost details of the system are shown in Table 2. The total cost of the system is about Rs. 70,000 (1989 prices). The economics will depend on the particular end use, capacity utilization, cost of biomass etc., and have to be worked out for case to case. Some promising applications are discussed below.

Decentralized Power Generation

Power plants with ratings of 100-500 kW operating on briquetting-gasification scheme can be visualized. However, due to the seasonal availability of biomass residues such as mustard stalks, cotton stalks etc., logistics related to collection of biomass and storage of briquettes will have to be worked out in detail.

Production of better quality fuel

A situation can be visualized in which customers would bring their biomass to a processing plant such as the one described here, and collect briquettes of an equal weight paying for the processing charges. Use of briquettes can result in reduced use of dung in the form of dung cakes burnt in devices such as the Hara. The briquettes can also be utilized in individual gasifier coupled pumpsets. Or the briquettes can be made into charcoal and sold in urban market. Processes for making charcoal-like material from biomass briquettes have been developed in Korea, Thailand etc.

Industrial applications

Residues such as saw-dust, groundnut shell, bamboo dust (from paper mills) etc. can be briquetted and gasified in-situ, and the gas can be used either in oil fired boilers or in diesel gensets, saving fuel-oil or diesel respectively. Briquettes of biomass waste

Table 1 : Parameters for processing mustard stalks to gasifier fuel

Process/ Parameter	Chopping	Pulverising	Briquetting	Cutting with circular saw
Bulk density after the process (kg/m^3)	94	219	268	79
Rate of processing (kg/hr)	110	73	163	20
Diesel consumption, lit/hr				
Diesel mode	.783	1.058	0.783	1.050
Dual fual mode	.196	0.312	0.196	0.262
Specific diesel Consumption, lit/kg				
Diesel mode	0.00712	0.01449	0.0048	0.0131
Dual fuel mode	0.00178	0.00427	0.0012	0.00328

produced in a factory making Ayurvedic compounds had been successly gasified in the present set up. Preliminary calculations indicated a pay-back period of 1½ years for the system. The proposed scheme of utilizing biomass residues thus seems to be immediately relevant to locations where biomass is readily available and where it often poses problems of disposal.

ACKNOWLEDGMENTS

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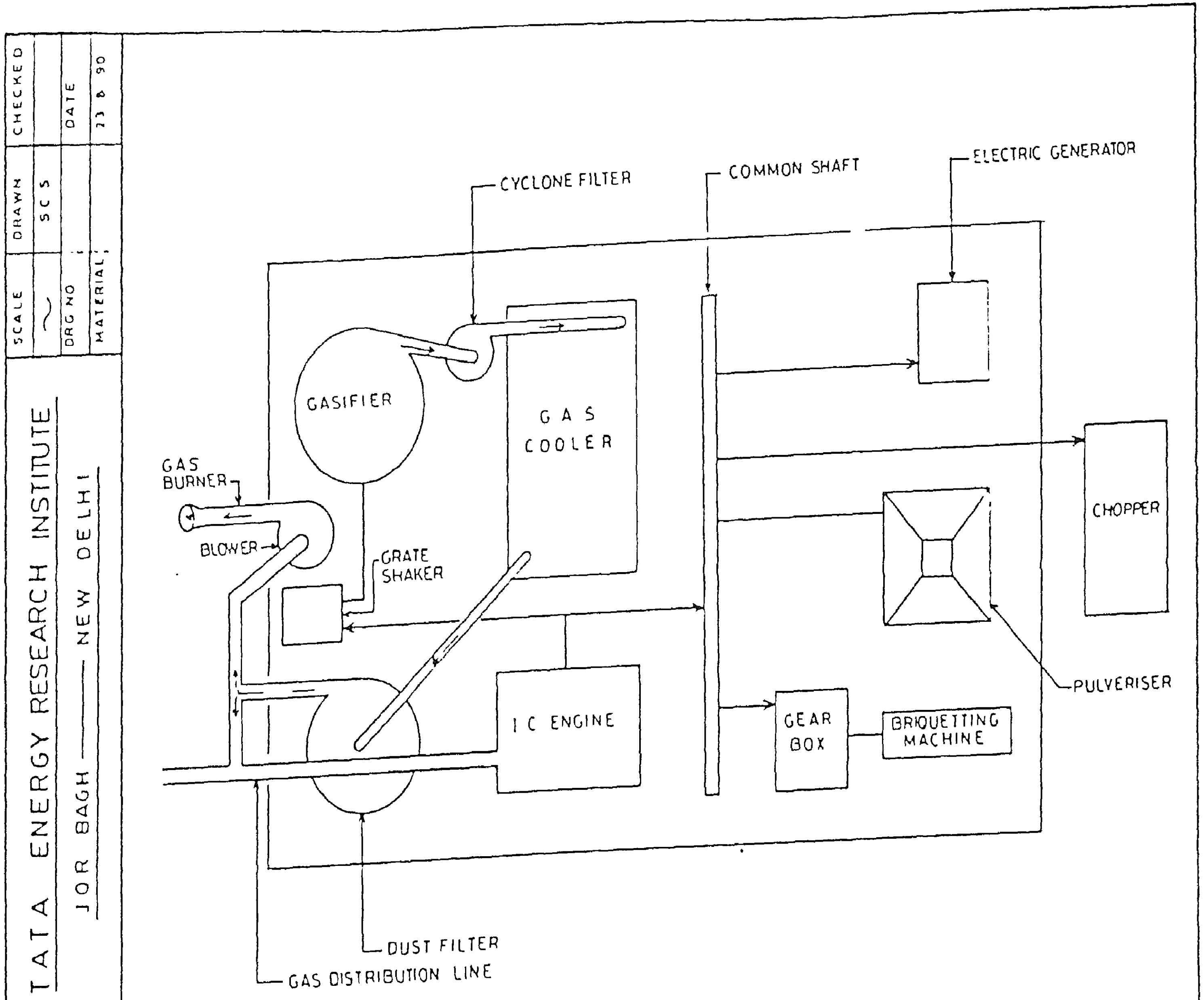
REFERENCES

1. P. Raman, S.D. Sharma and V.V.N. Kishore, `Studies on a briquetting - gasification system for utilization of biomass residues', Proceedings of the 1st National meet on recent advances in biomass gasification technology, I.I.T. Bombay, pp 61-65, 1989.

2. P. Raman, S.D. Sharma, S. Kohli and V.V.N. Kishore, Design and test performance of a throatless downdraft gasifier with low specific gasification rate, Renewable Energy for Rural Development, V.V.N. Kishore and N.K. Bansal (eds), Tata McGraw-Hill New Delhi, pp 568-573, 1989

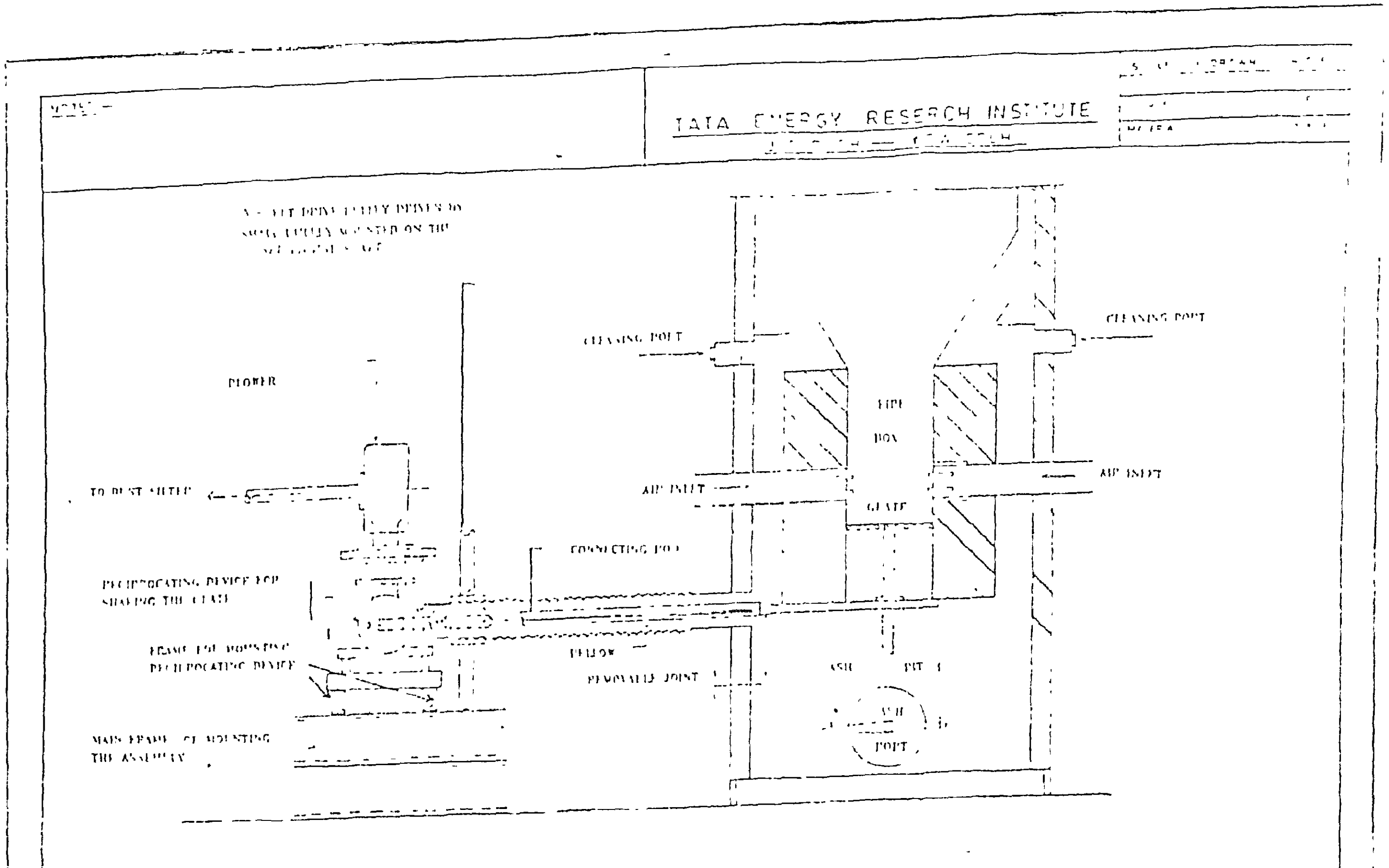
Table 2 : Cost details of the system

Trolly for assembling the system	Rs. 14,000.00
Gasifier	Rs. 10,000.00
Cyclone filter	Rs. 500.00
Gas cooler	Rs. 3,000.00
Dust filter	Rs. 500.00
Grate shaking unit	Rs. 2,000.00
Gas distribution line (Pipes & fitting, valves etc.)	Rs. 2,000.00
Blower for ignition	Rs. 1,000.00
Common shaft, pulleys, bearing etc.	Rs. 4,000.00
Alternator (7KVA)	Rs. 6,000.00
Diesel Engine (10 H.P.)	Rs. 6,000.00
Pulveriser	Rs. 5,000.00
Briquetting machine	Rs. 5,000.00
Chopper	Rs. 2,000.00
Assembling charges	Rs. 3,000.00
	Rs. 64,000.00
Miscellaneous	Rs. 6,000.00
Total	Rs. 70,000.00



BLOCK DIAGRAM FOR BIOMASS GASIFIER SYSTEM

Figure 1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V-BELT DRIVE PULLEY DRIVEN BY
PULLEY MOUNTED ON THE
BLOWER
TO DUST FILTER
RECIPROCATING DEVICE FOR SHAKING THE GRATE
FRAME FOR MOUNTING RECIPROCATING DEVICE
MAIN FRAME FOR MOUNTING THE ASSEMBLY
CLEANING PORT
CLEANING PORT
FIRE BOX
AIR INLET
AIR INLET
GRATE
CONNECTING ROD
BELLOW
REMOVABLE JOINT
ASH PIT
ASH PORT

GRATE SHAKING SYSTEM

Figure 3

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A THROATLESS DOWNDRAFT BIOMASS GASIFIER WITH CONTINUOUS ASH REMOVAL

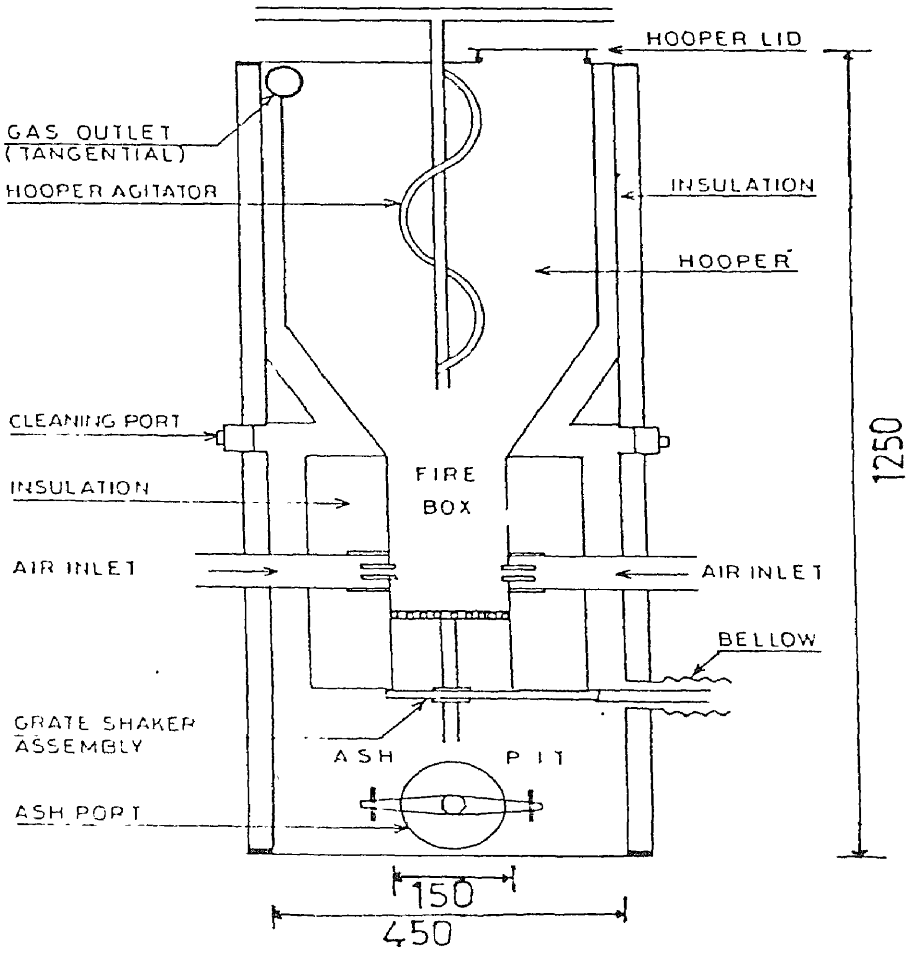

Figure 2.

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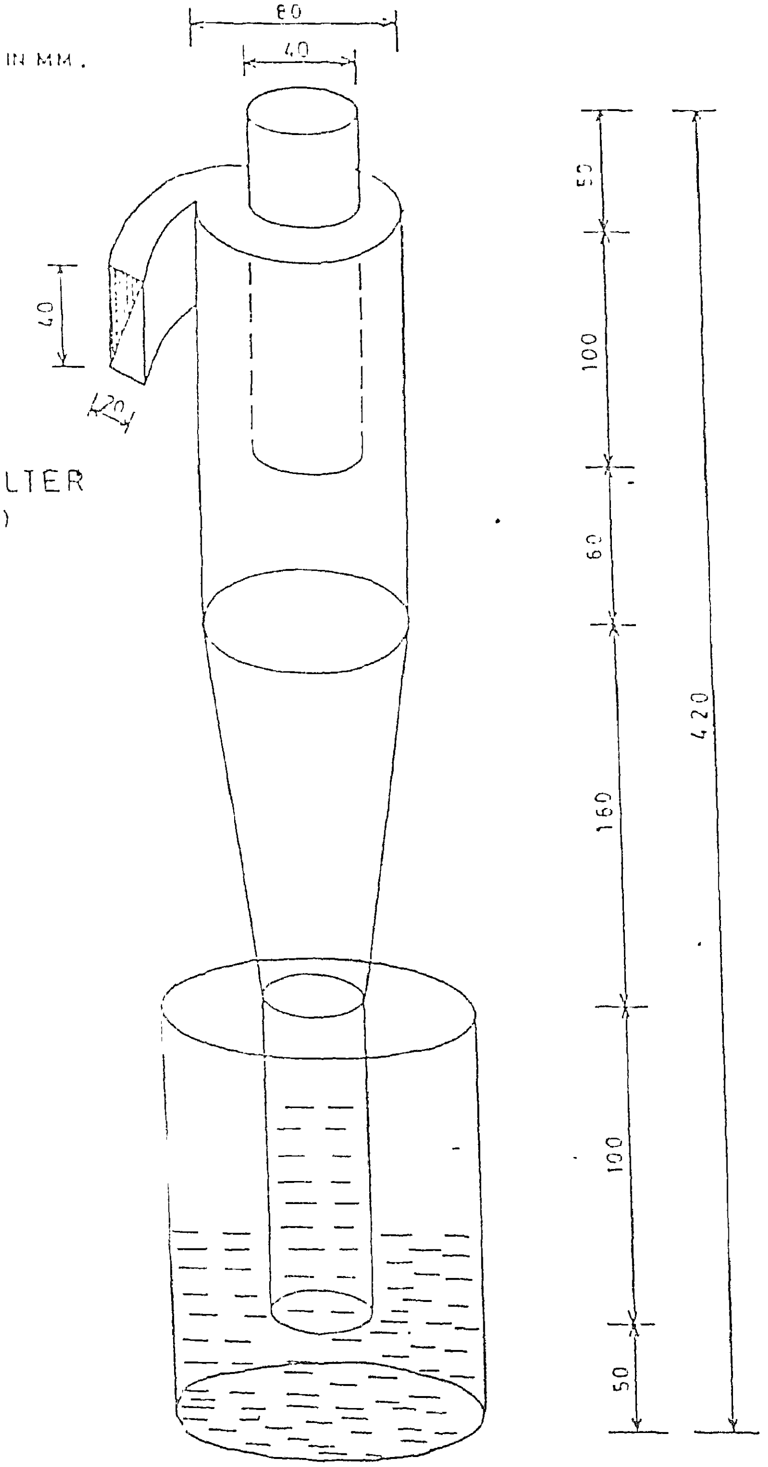

CYCLONE FILTER
(FOR 10 HP)

Figure 4

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GAS COOLER

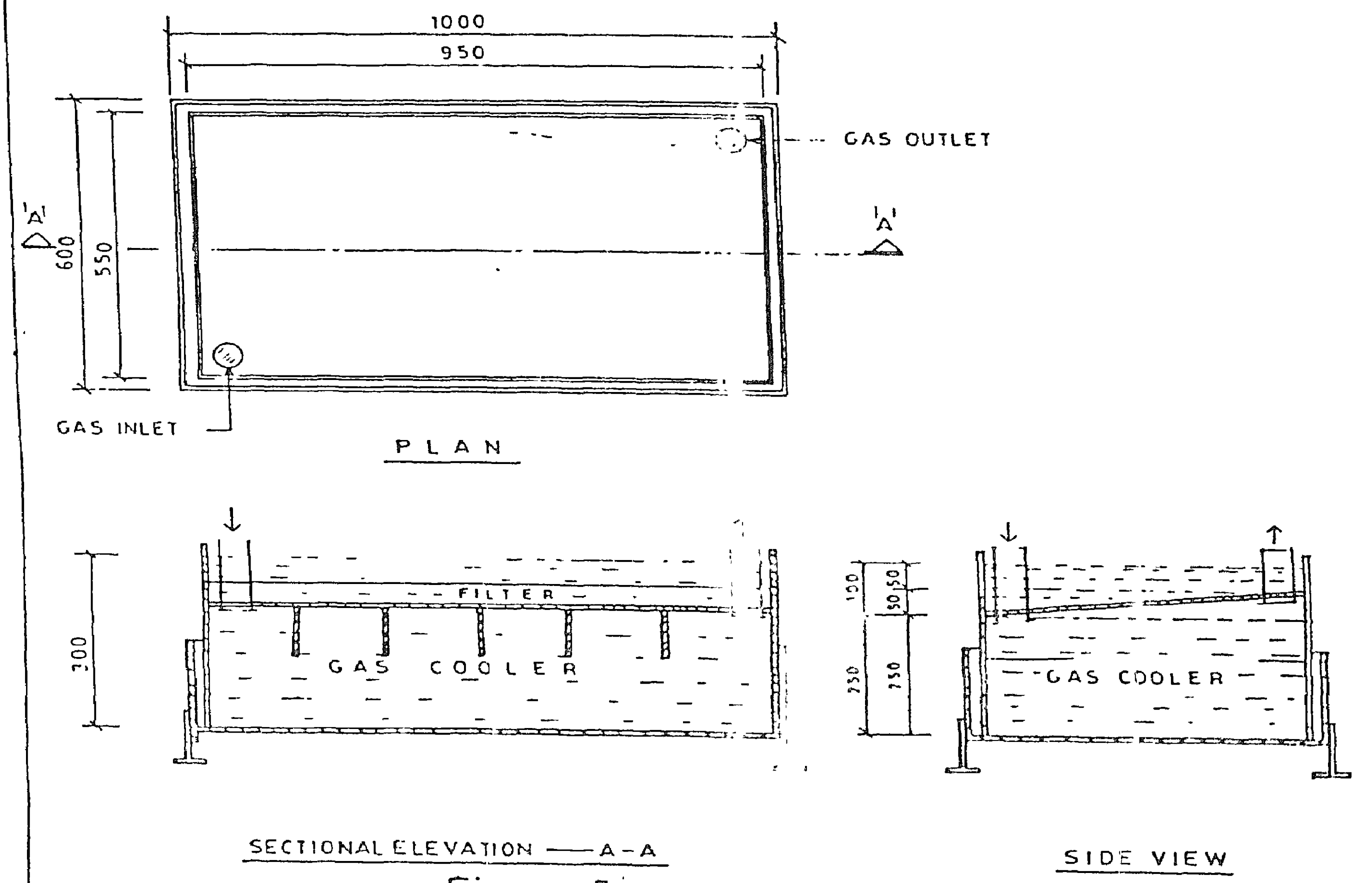

Figure 5.

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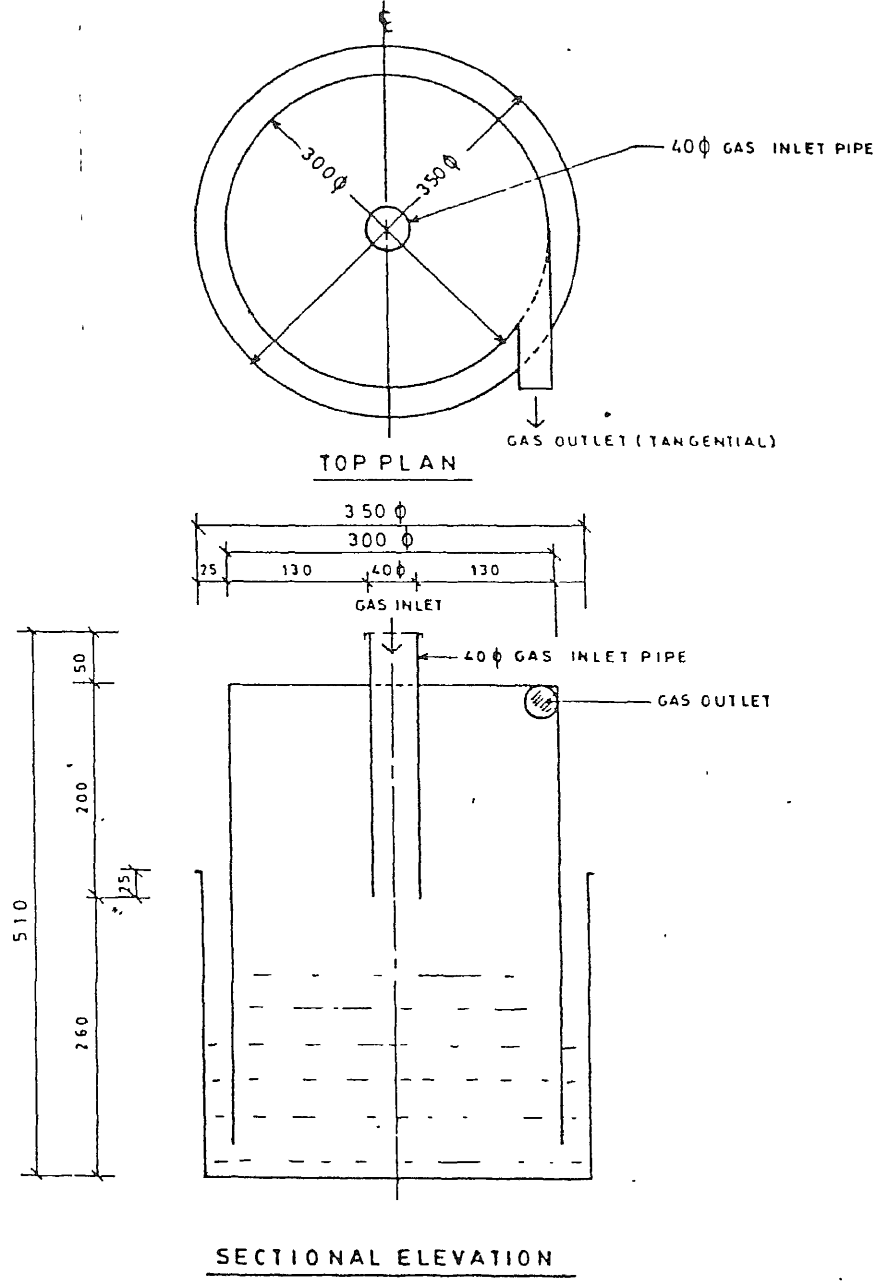

Figure 6.

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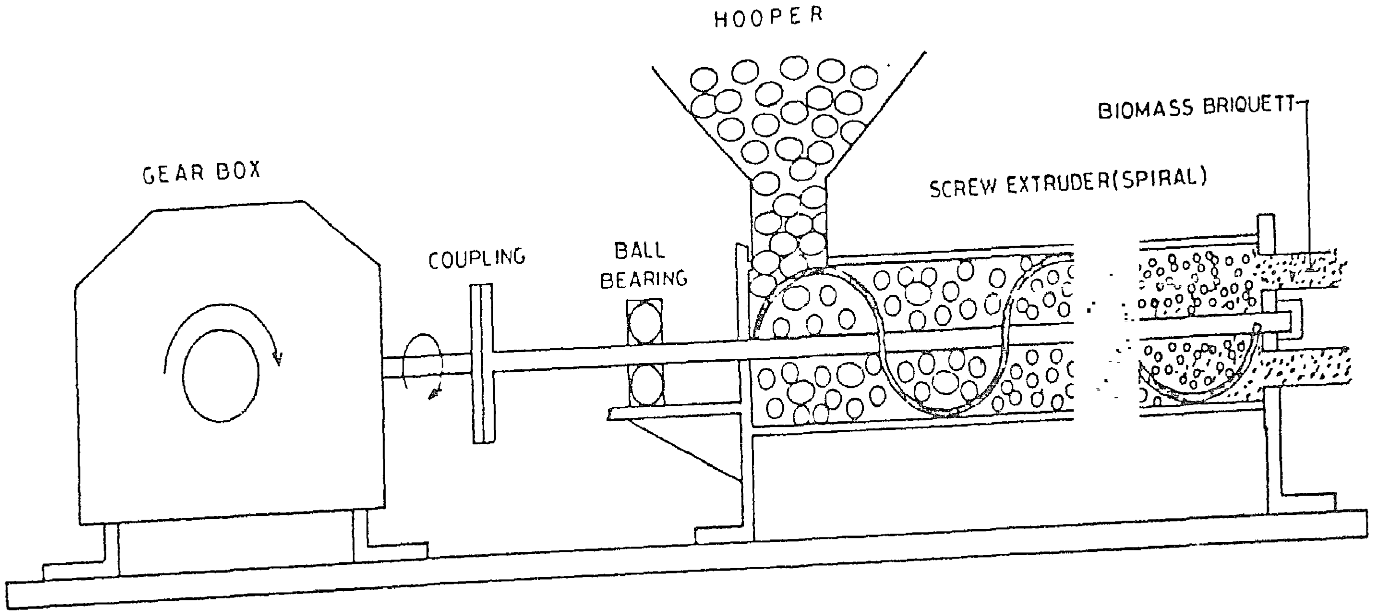

BRIQUETTING MACHINE FOR BIOMASS

Figure 7.

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Figure 10.

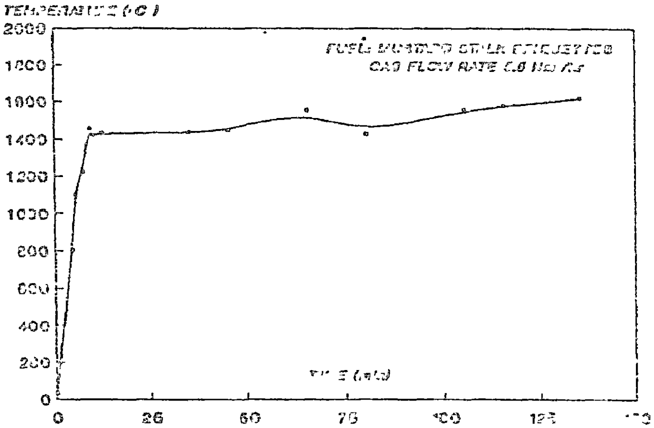

FIG. 11. RADIAL TEMPERATURE PROFILE ACROSS THE AIR NOZZLES FOR A SPECIFIC GASIFICATION RATE OF ABOUT 0 08 Nm /cm hr

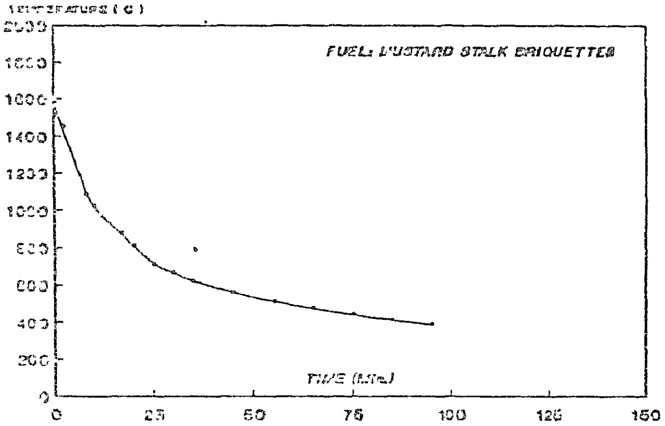

FIG 12: TEMPERATURE HISTORY IN THE FIRE BOX DURING COOLING OFF

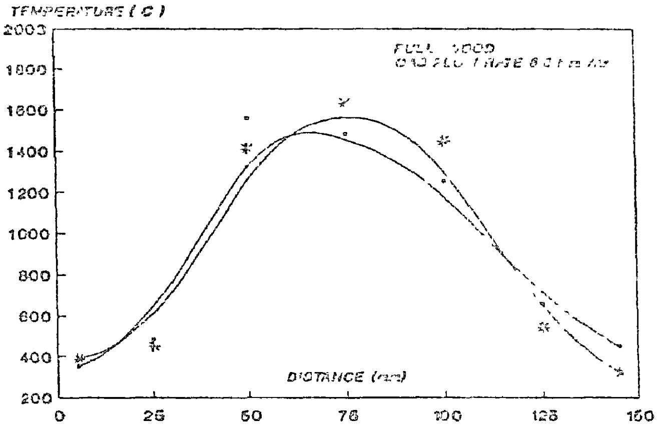

FIG. 13: RADIAL TEMPERATURE PROFILE ACROSS THE AIR NOZZLES FOR A SPECIFIC GASIFICATION RATE OF ABOUT 0 03 Nm /cm hr.

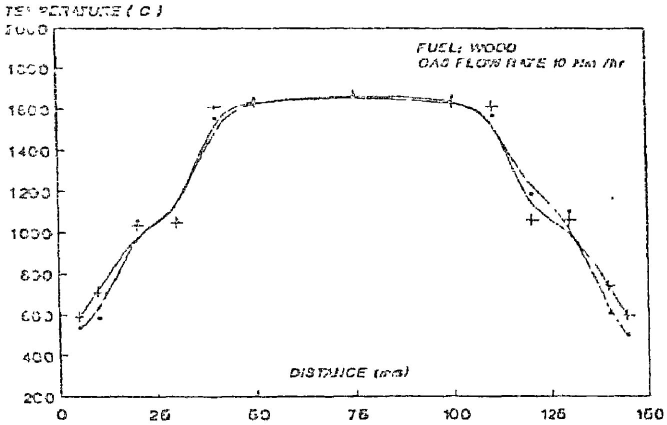

FIG 14: RADIAL TEMPERATURE PROFILE FOR AN SGR OF ABOUT 0 06 Nm /cm hr.

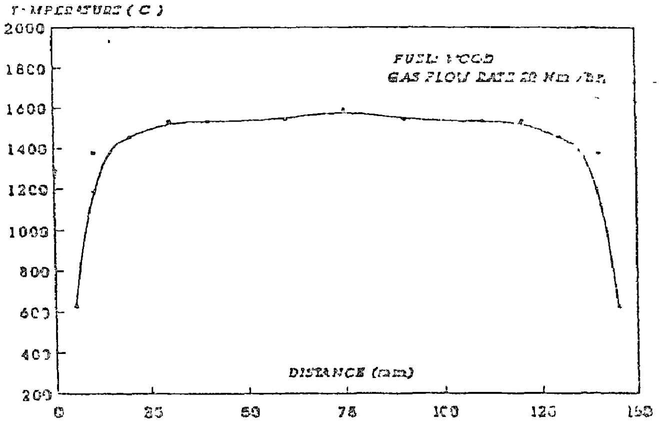

FIG 15: RADIAL TEMPERATURE PROFILE FOR AN SGR OF ABOUT 0.11 Nm /cm hr.

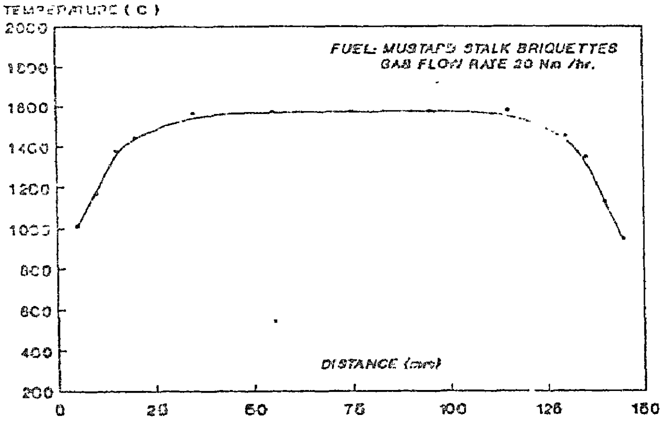

FIG. 16: RADIAL TEMPERATURE PROFILE FOR AN SGR OF ABOUT 0.11 Nm /cm hr.

[illegible]

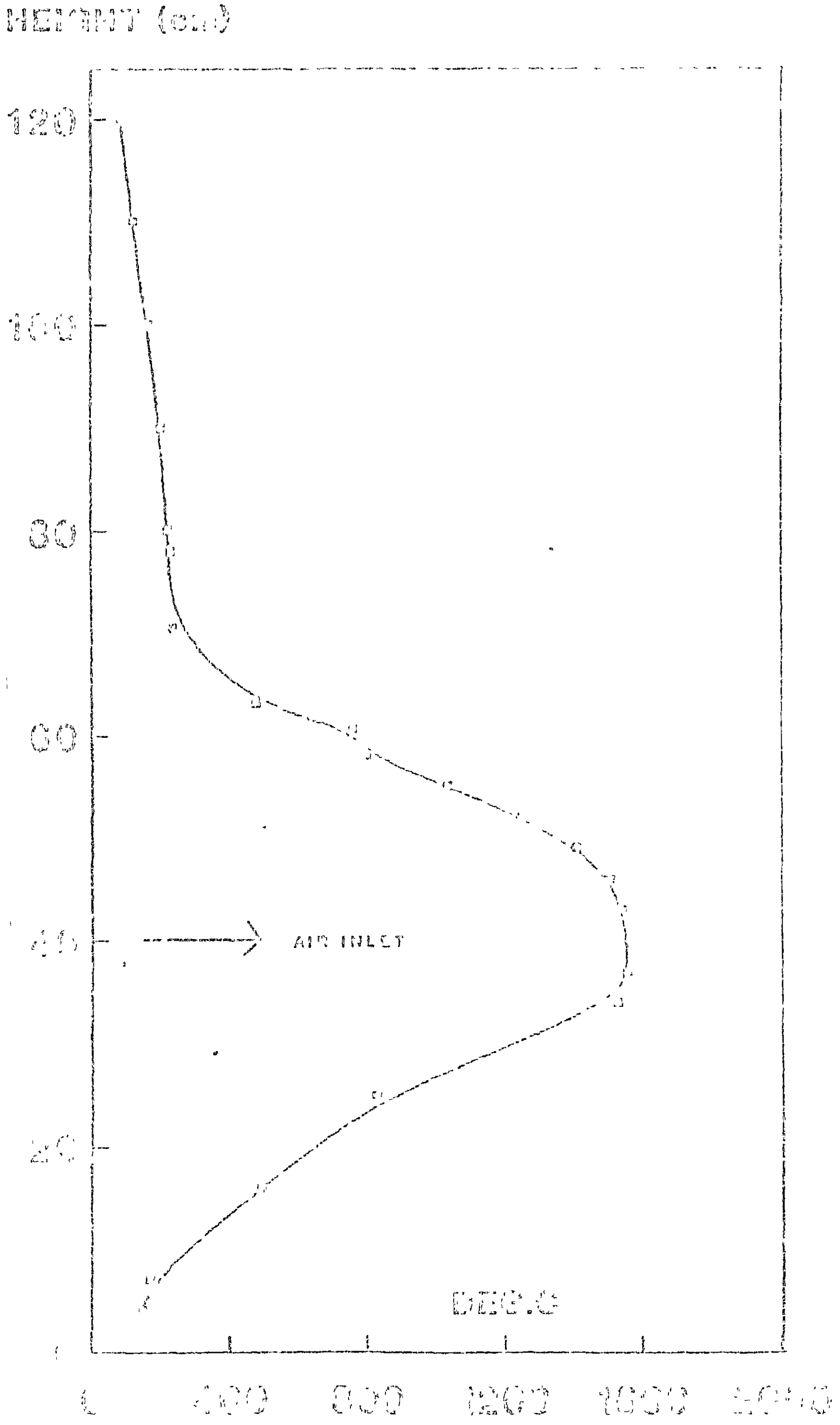

FIG [illegible] TEMPERATURE PROFILE IN THE GASIFIER